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Discover the wonders of the universe

2015 sees us filling in some of the gaps in our photographic account of the Solar System. The inner planets have been thoroughly documented by several decades of probes and orbiters, while the gas giants are still the subject of scrutiny, for some of the most stunning space images since the Apollo mission captured the 'Earthrise' on the horizon of the Moon.

So what's next? At the time of writing, NASA's Dawn mission is nearing its rendezvous with the mysterious dwarf planet Ceres, the 950-kilometre (590-mile)-diameter space rock made conspicuous by taking up around a third of the total mass of the Asteroid Belt. Discovered over 200 years ago, a close-up image of Ceres has long been anticipated.

Another major mission we can look forward to this year is the arrival of New Horizons at Pluto in July. This was in no way diminished by the fact that this former planet was downgraded to dwarf planet status in the same year as the spacecraft's launch. New Horizons aims to gather data and take images in unprecendented detail. Currently, the best quality image of Pluto we have amounts to little more than a spherical blob. With the spacecraft buzzing past Pluto in its fly-by, we should be able to determine the surface features and composition of Pluto, as well as its moons and other objects in the cold, dark depths at the fringes of the Solar System.

Ben Biggs
Editor

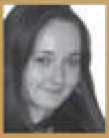
> "There is a 98 per cent probability that the star crossed the Solar System"
>
> **Dr Ralf-Dieter Scholz, Leibniz Institute for Astrophysics Potsdam (AIP)**

Crew roster

David Crookes

■ Dave has kept tabs on the Dawn Mission ever since Vesta: read about Ceres on page 26

Gemma Lavender



■ Gemma bags two science celebrities for her new Earth feature this issue, on page 36

Nigel Watson

■ Ever heard of the rover with six legs? There's no puchline, just Nigel's top ten rovers on p.52

Laura Mears

■ Laura celebrates the silver anniversary of Hubble with a photo extravaganza

Expedition 42 returns to Earth in the Soyuz capsule after six months aboard the International Space Station

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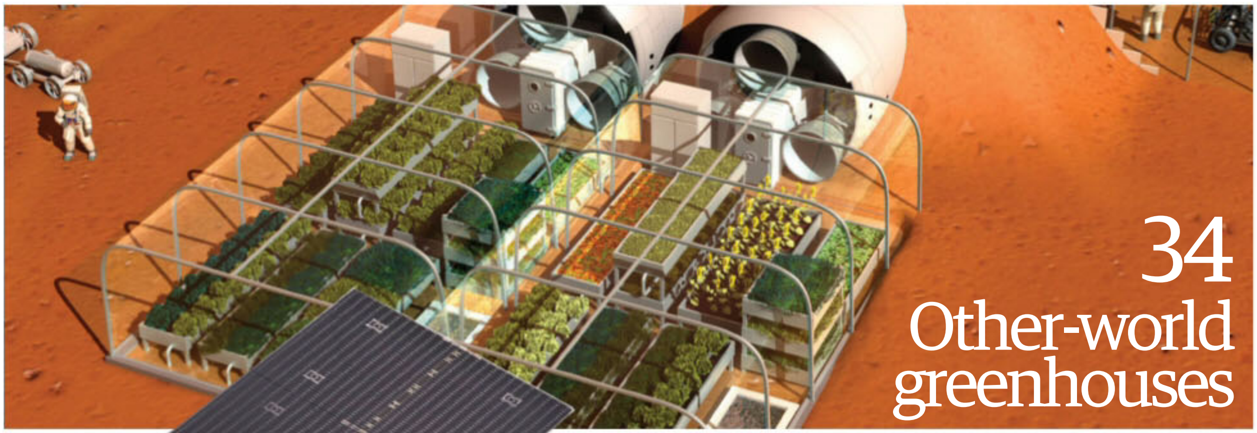

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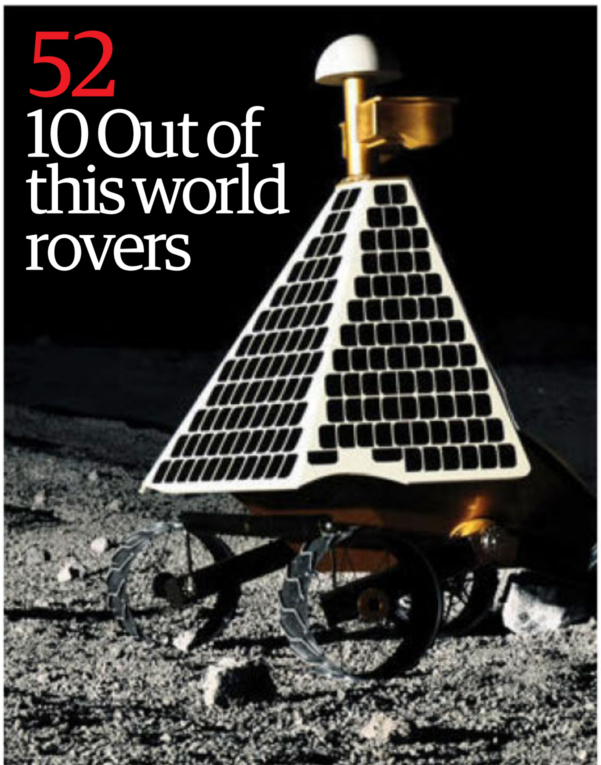

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Ben Biggs
Editor

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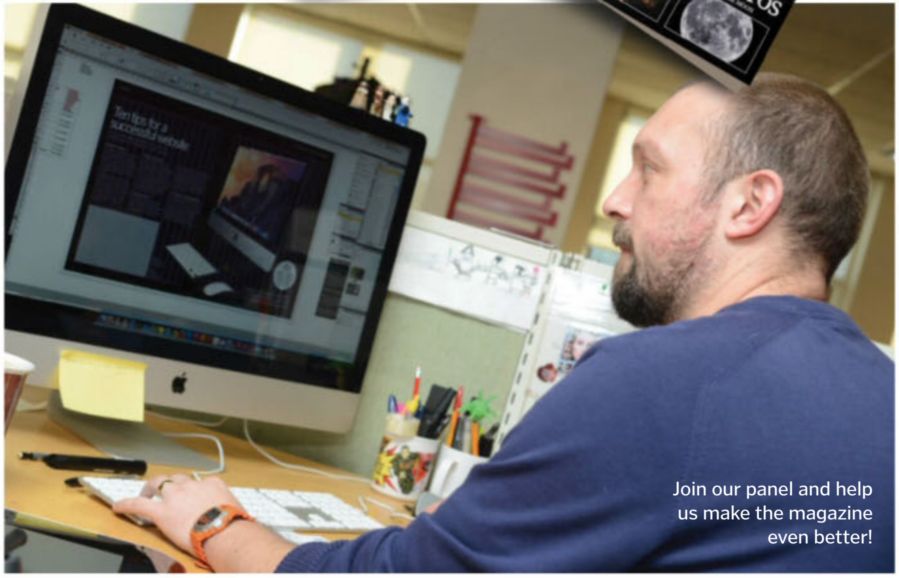

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HUBBLE'S GREATEST DISCOVERIES

Join us as we take a tour of our favourite images by this iconic space telescope

Written by Laura Mears

The Hubble Ultra-Deep Field

INTERVIEW BIO

Dr Mario Livio

Senior astrophysicist at the Hubble Space Telescope Science Institute

Dr Mario Livio is an astrophysicist specialising in exciting stuff like black holes, neutron stars, white dwarfs and supernova explosions. He has worked with Hubble at the Space Telescope Science Institute since 1991 and has published over 400 scientific papers and five popular science books.

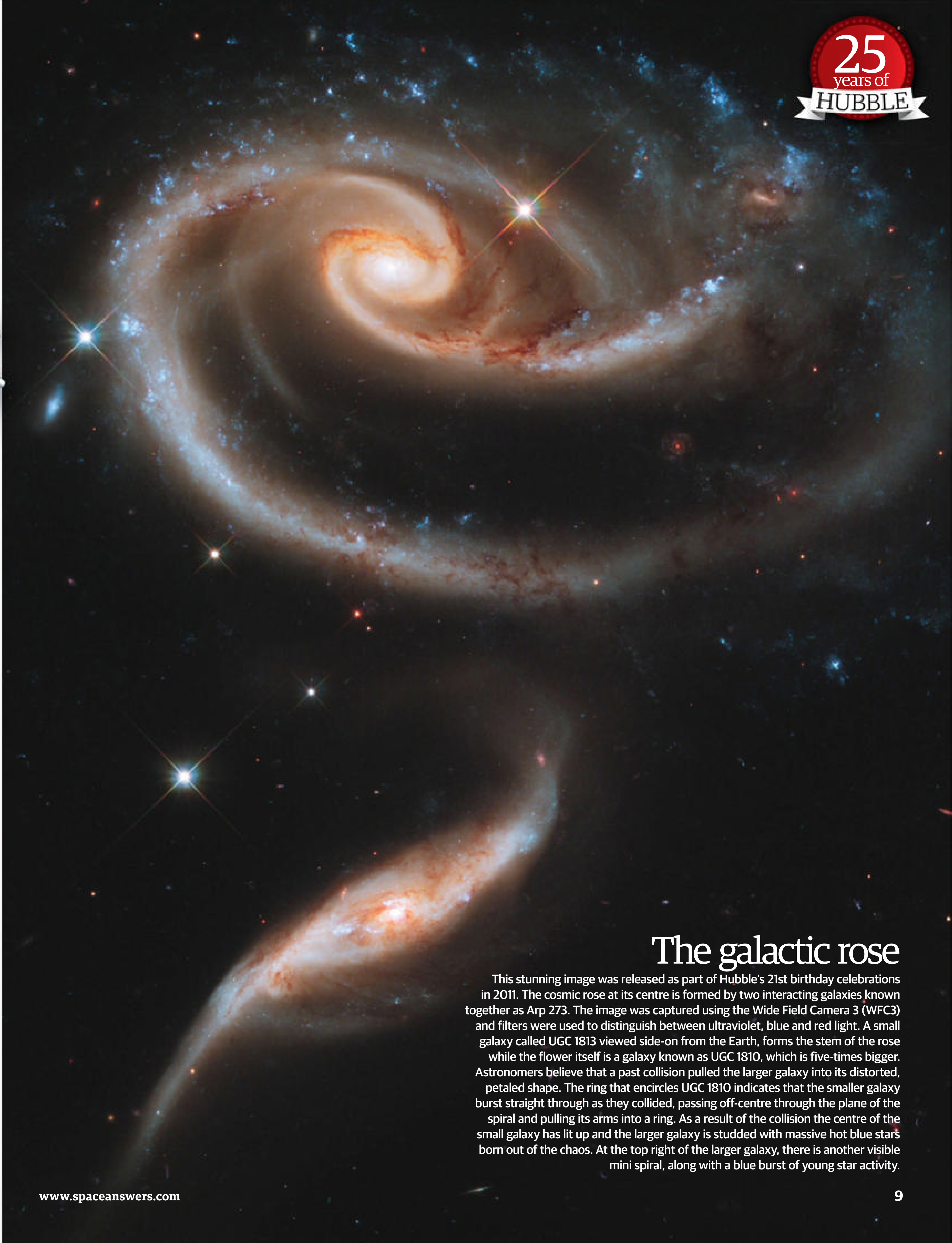
This year, the Hubble Space Telescope is celebrating its 25th year in space. Over the past two and a half decades, it has made more than a million observations, provided the data for over 10,000 scientific publications and it has given us a breathtaking window out into the far reaches of the universe from its position beyond the haze of our atmosphere.

Hubble was the brainchild of American astrophysicist Lyman Spitzer Jr. and its construction took almost a decade, completed in 1985. However, its journey into space was complicated. Its launch was delayed by the Challenger disaster in 1986, which claimed the lives of seven astronauts and by the time it finally arrived in orbit in April 1990, its first images were blurry. To the dismay of the team, the carefully crafted 2.4-metre (94.5-inch) mirror had a spherical aberration, a microscopic fault that prevented the light being properly focussed.

Hubble was designed to be able to dock with the Space Shuttle, allowing repairs and upgrades to be performed in space. A series of corrective mirrors were installed by intrepid astronauts in a week-long mission in 1993, acting like a pair of glasses and bringing the light into focus. Since the repair the telescope has been upgraded on a further four occasions and has gone on to capture thousands of stunning, high-resolution and iconic images.

Hubble is responsible for some of the biggest scientific discoveries of the space age. It showed that dark energy is accelerating the expansion of the universe and allowed scientists to pinpoint its age to between 13 and 14 billion years. And it has shown that there are supermassive black holes at the centres of almost all galaxies.

In its 25 illustrious years in space, Hubble has taken some of the most breathtaking images of the cosmos and in the process this amazing feat of engineering has captured the hearts and minds of the adoring public like no other space telescope has done before. ▢



The galactic rose

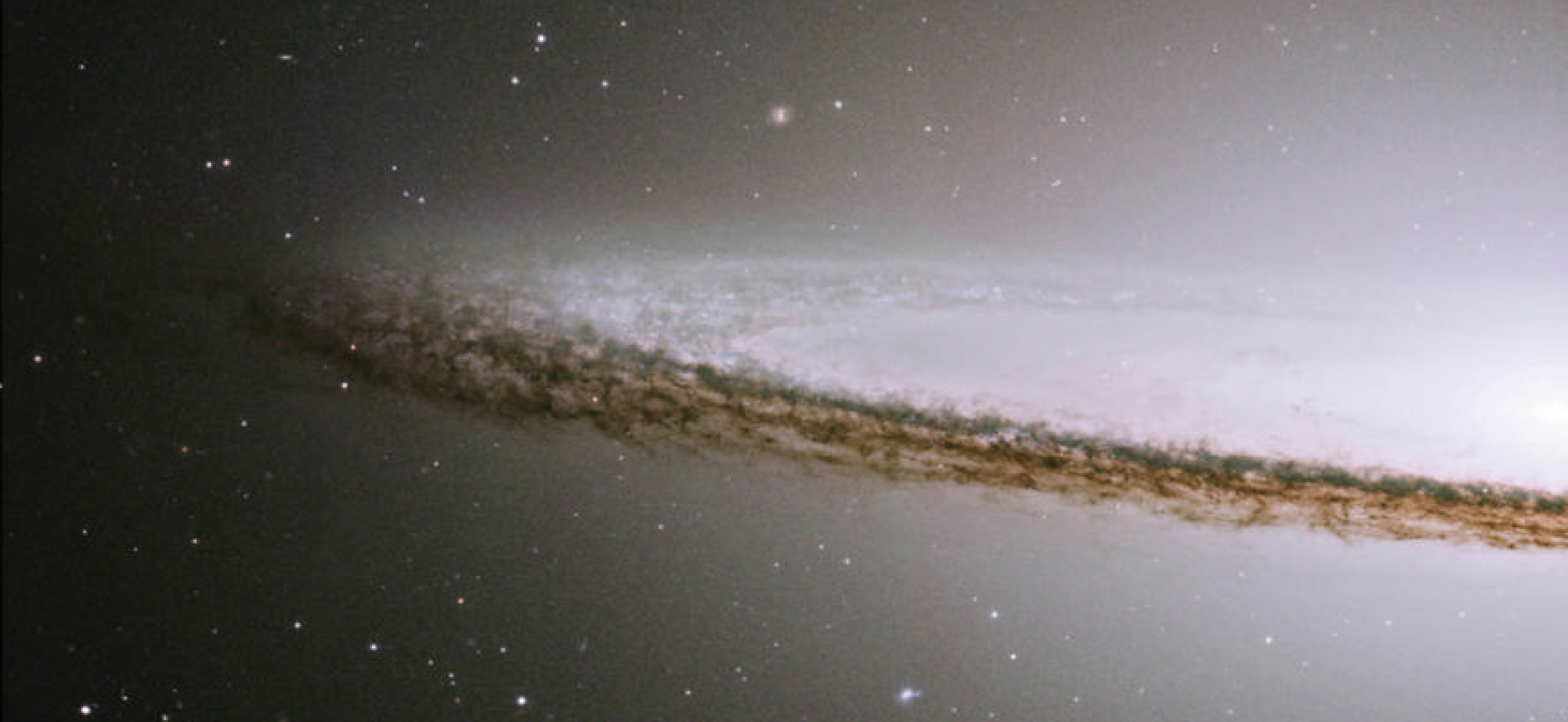
This stunning image was released as part of Hubble's 21st birthday celebrations in 2011. The cosmic rose at its centre is formed by two interacting galaxies known together as Arp 273. The image was captured using the Wide Field Camera 3 (WFC3) and filters were used to distinguish between ultraviolet, blue and red light. A small galaxy called UGC 1813 viewed side-on from the Earth, forms the stem of the rose while the flower itself is a galaxy known as UGC 1810, which is five-times bigger. Astronomers believe that a past collision pulled the larger galaxy into its distorted, petaled shape. The ring that encircles UGC 1810 indicates that the smaller galaxy burst straight through as they collided, passing off-centre through the plane of the spiral and pulling its arms into a ring. As a result of the collision the centre of the small galaxy has lit up and the larger galaxy is studded with massive hot blue stars born out of the chaos. At the top right of the larger galaxy, there is another visible mini spiral, along with a blue burst of young star activity.

The sombrero galaxy

This incredibly detailed image of M104 was captured by the Hubble's Advanced Camera for Surveys. It is one of the biggest Hubble images ever taken, and it was stitched together from six separate exposures and used red, green and blue filters to create a true-colour representation.

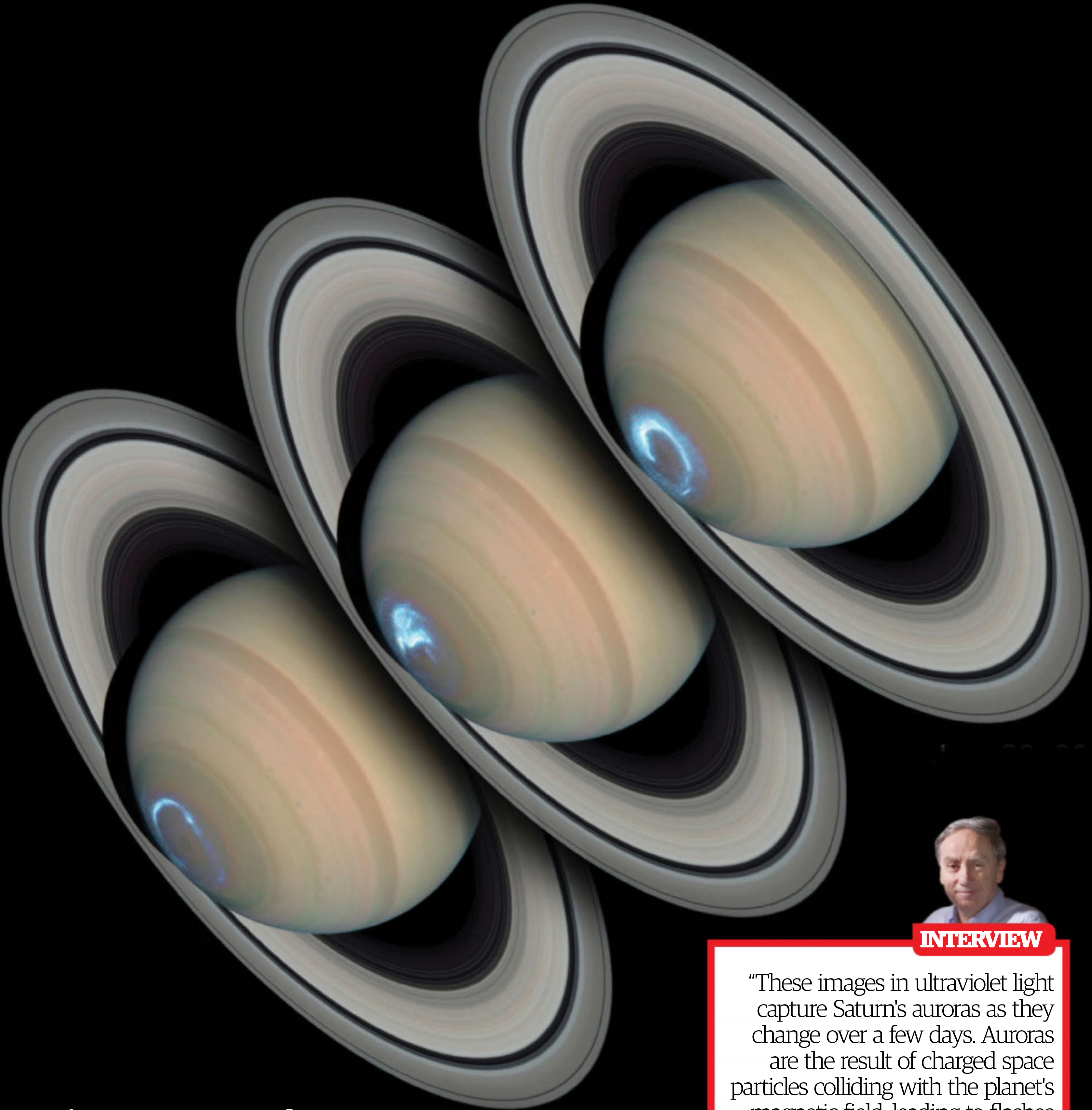
The galaxy, nicknamed the sombrero galaxy after its wide, flat shape, is one of the most massive objects in the Virgo cluster. It was originally thought to be a star, but is moving away from us at speeds of over 1,127 kilometres (700 miles) per second and it is now known to measure 50,000 light years in diameter. It is almost the same age as the Milky Way, with globular clusters dating back 10 to 13 billion years.

In the very centre is a second disc, which appears at an angle to the main disc of the galaxy. It emits bright X-ray radiation and is thought to belong to a supermassive black hole measuring one billion solar masses.



INTERVIEW

"This visually stunning galaxy is about 28 million light-years from Earth. We view it almost edge-on. The main reason I like this image is that Hubble has captured the dust lanes in the galactic ring that surrounds the central bulge with such a resolution that the image looks almost three-dimensional. Around the galaxy you can see a collection of between 1,000 and 2,000 globular star clusters. This is about ten-times more than the number of clusters that surround the Milky Way."



The auroras of Saturn

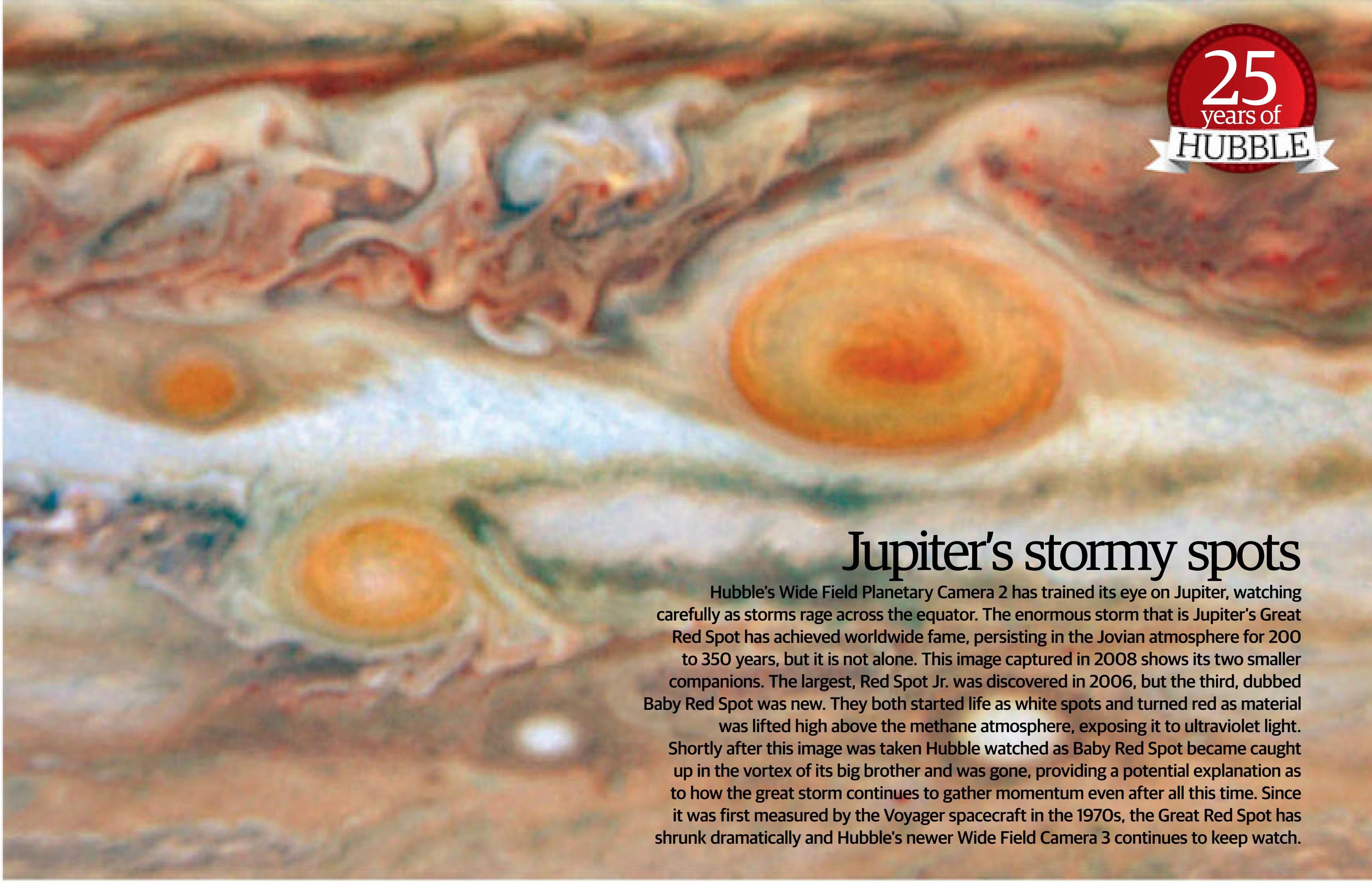
In 2003, Hubble collaborated with the Cassini spacecraft to monitor the auroras in Saturn's atmosphere. Hubble's Advanced Camera for Surveys captured the visible light images of the outline of the planet and its Space Telescope Imaging Spectrograph revealed the ultraviolet glow of the auroras as they moved through the atmosphere. What they saw was auroras that last for days on end and glow bright throughout.

With Cassini's help, we know that these auroras are created by pressure changes in Saturn's atmosphere. As the solar wind increases, the auroras brighten and shrink in diameter.

Although the aurora seems to glow a bright, icy blue in this image, on the surface of Saturn the spectacle would appear to be quite different. As the blue-ish ultraviolet light hits the atmosphere it excites hydrogen atoms making them glow red. On Earth we see something similar, except that in our atmosphere of nitrogen and oxygen, the dominant colours would be green and blue.

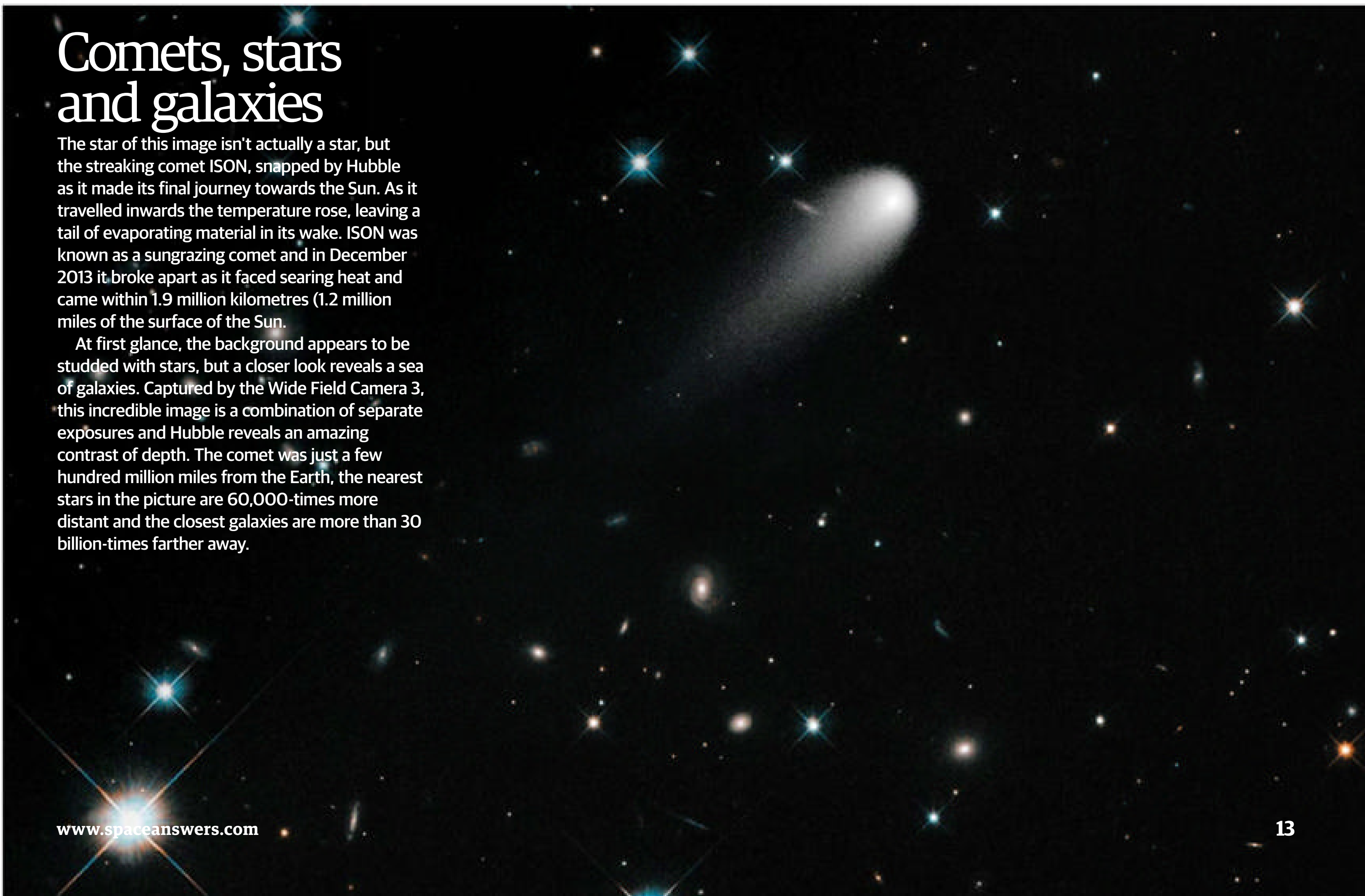
INTERVIEW

"These images in ultraviolet light capture Saturn's auroras as they change over a few days. Auroras are the result of charged space particles colliding with the planet's magnetic field, leading to flashes produced by gas in its atmosphere. The emission is in the form of radio waves and ultraviolet light. An increase in the intensity of the emission is accompanied the emission ring shrinking. This particular behaviour is different from those observed in the auroras of both the Earth and Jupiter."



Jupiter's stormy spots

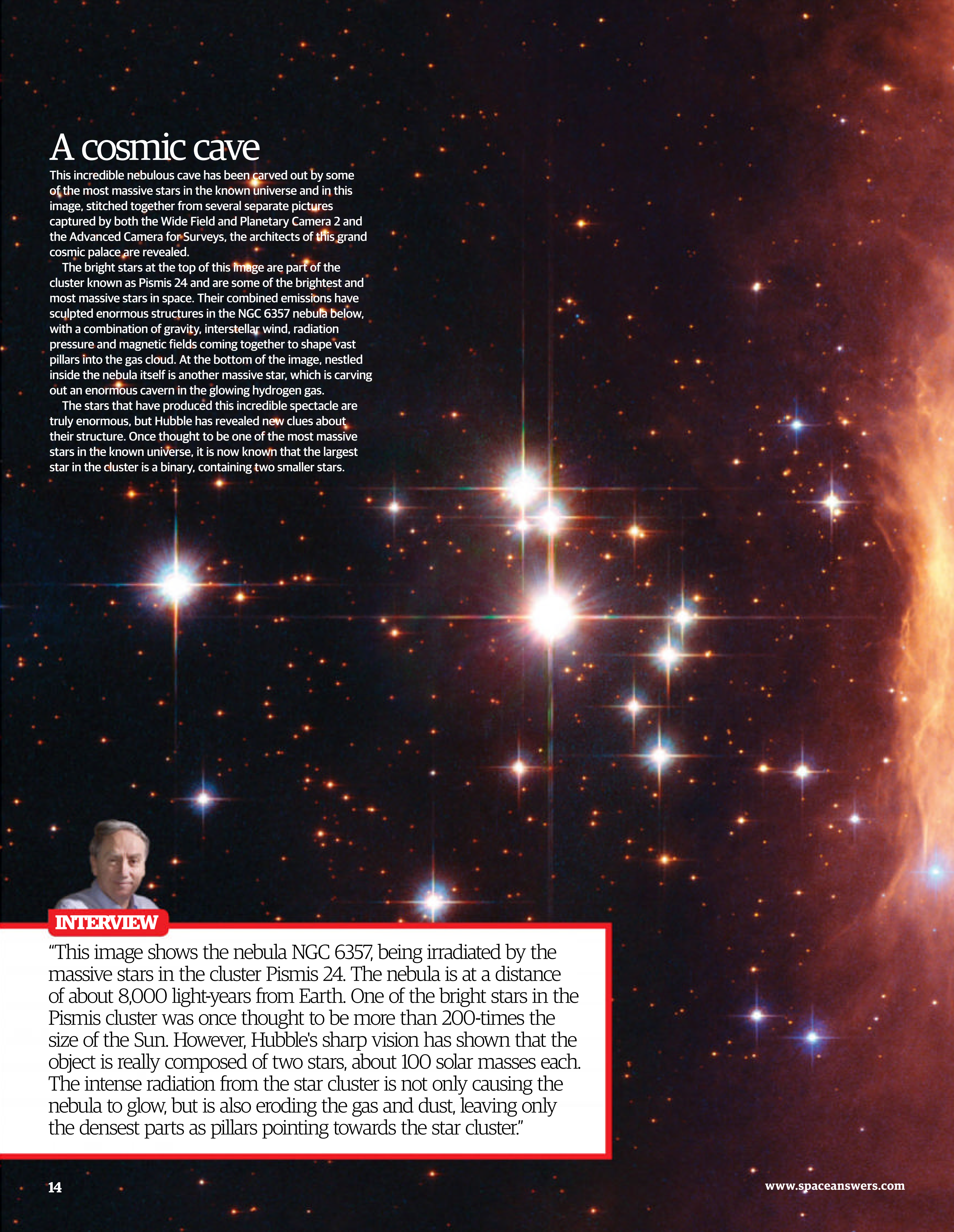
Hubble's Wide Field Planetary Camera 2 has trained its eye on Jupiter, watching carefully as storms rage across the equator. The enormous storm that is Jupiter's Great Red Spot has achieved worldwide fame, persisting in the Jovian atmosphere for 200 to 350 years, but it is not alone. This image captured in 2008 shows its two smaller companions. The largest, Red Spot Jr. was discovered in 2006, but the third, dubbed Baby Red Spot was new. They both started life as white spots and turned red as material was lifted high above the methane atmosphere, exposing it to ultraviolet light. Shortly after this image was taken Hubble watched as Baby Red Spot became caught up in the vortex of its big brother and was gone, providing a potential explanation as to how the great storm continues to gather momentum even after all this time. Since it was first measured by the Voyager spacecraft in the 1970s, the Great Red Spot has shrunk dramatically and Hubble's newer Wide Field Camera 3 continues to keep watch.



Comets, stars and galaxies

The star of this image isn't actually a star, but the streaking comet ISON, snapped by Hubble as it made its final journey towards the Sun. As it travelled inwards the temperature rose, leaving a tail of evaporating material in its wake. ISON was known as a sungrazing comet and in December 2013 it broke apart as it faced searing heat and came within 1.9 million kilometres (1.2 million miles of the surface of the Sun.

At first glance, the background appears to be studded with stars, but a closer look reveals a sea of galaxies. Captured by the Wide Field Camera 3, this incredible image is a combination of separate exposures and Hubble reveals an amazing contrast of depth. The comet was just a few hundred million miles from the Earth, the nearest stars in the picture are 60,000-times more distant and the closest galaxies are more than 30 billion-times farther away.



A cosmic cave

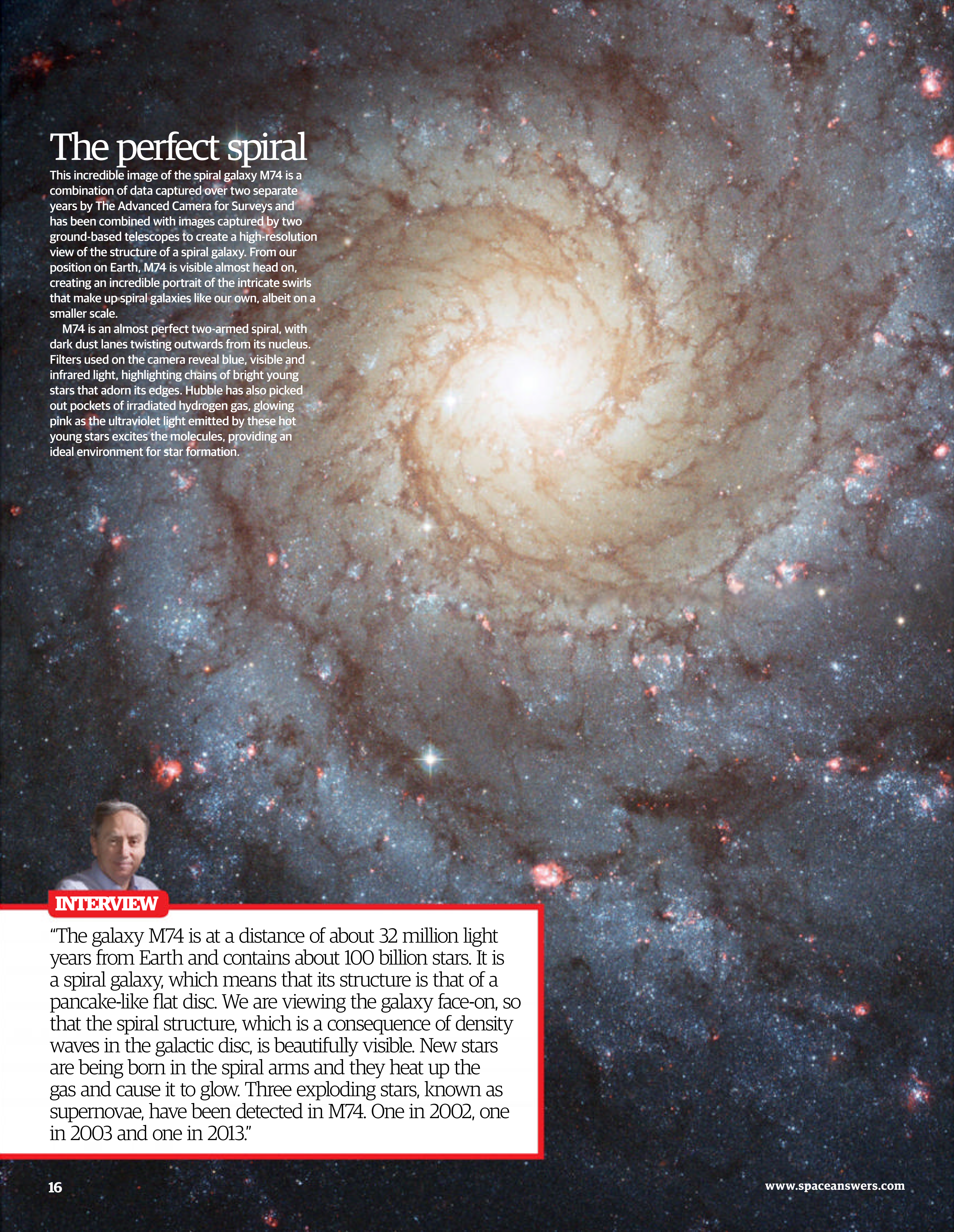
This incredible nebulous cave has been carved out by some of the most massive stars in the known universe and in this image, stitched together from several separate pictures captured by both the Wide Field and Planetary Camera 2 and the Advanced Camera for Surveys, the architects of this grand cosmic palace are revealed.

The bright stars at the top of this image are part of the cluster known as Pismis 24 and are some of the brightest and most massive stars in space. Their combined emissions have sculpted enormous structures in the NGC 6357 nebula below, with a combination of gravity, interstellar wind, radiation pressure and magnetic fields coming together to shape vast pillars into the gas cloud. At the bottom of the image, nestled inside the nebula itself is another massive star, which is carving out an enormous cavern in the glowing hydrogen gas.

The stars that have produced this incredible spectacle are truly enormous, but Hubble has revealed new clues about their structure. Once thought to be one of the most massive stars in the known universe, it is now known that the largest star in the cluster is a binary, containing two smaller stars.

INTERVIEW

"This image shows the nebula NGC 6357, being irradiated by the massive stars in the cluster Pismis 24. The nebula is at a distance of about 8,000 light-years from Earth. One of the bright stars in the Pismis cluster was once thought to be more than 200-times the size of the Sun. However, Hubble's sharp vision has shown that the object is really composed of two stars, about 100 solar masses each. The intense radiation from the star cluster is not only causing the nebula to glow, but is also eroding the gas and dust, leaving only the densest parts as pillars pointing towards the star cluster."



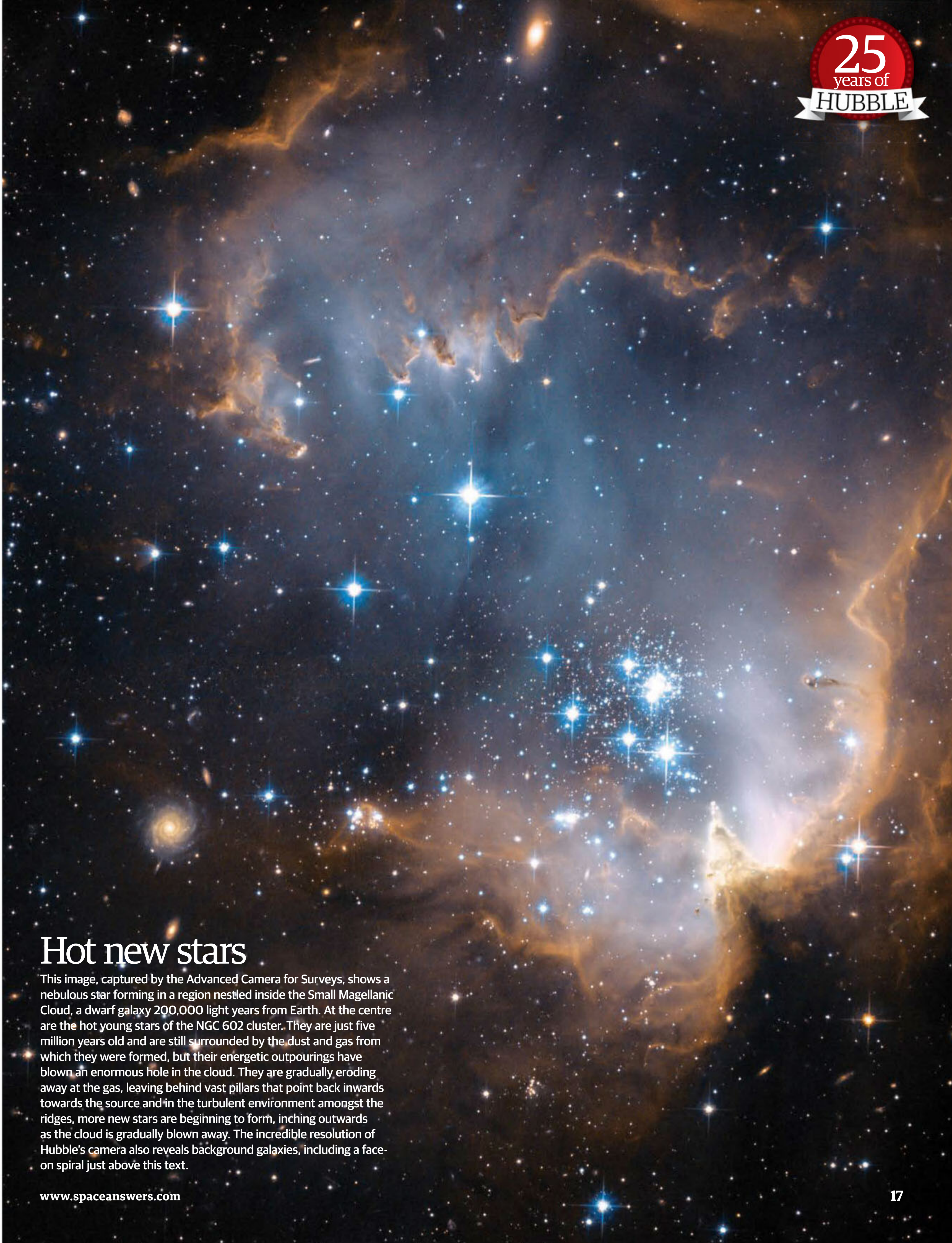
The perfect spiral

This incredible image of the spiral galaxy M74 is a combination of data captured over two separate years by The Advanced Camera for Surveys and has been combined with images captured by two ground-based telescopes to create a high-resolution view of the structure of a spiral galaxy. From our position on Earth, M74 is visible almost head on, creating an incredible portrait of the intricate swirls that make up spiral galaxies like our own, albeit on a smaller scale.

M74 is an almost perfect two-armed spiral, with dark dust lanes twisting outwards from its nucleus. Filters used on the camera reveal blue, visible and infrared light, highlighting chains of bright young stars that adorn its edges. Hubble has also picked out pockets of irradiated hydrogen gas, glowing pink as the ultraviolet light emitted by these hot young stars excites the molecules, providing an ideal environment for star formation.

INTERVIEW

"The galaxy M74 is at a distance of about 32 million light years from Earth and contains about 100 billion stars. It is a spiral galaxy, which means that its structure is that of a pancake-like flat disc. We are viewing the galaxy face-on, so that the spiral structure, which is a consequence of density waves in the galactic disc, is beautifully visible. New stars are being born in the spiral arms and they heat up the gas and cause it to glow. Three exploding stars, known as supernovae, have been detected in M74. One in 2002, one in 2003 and one in 2013."

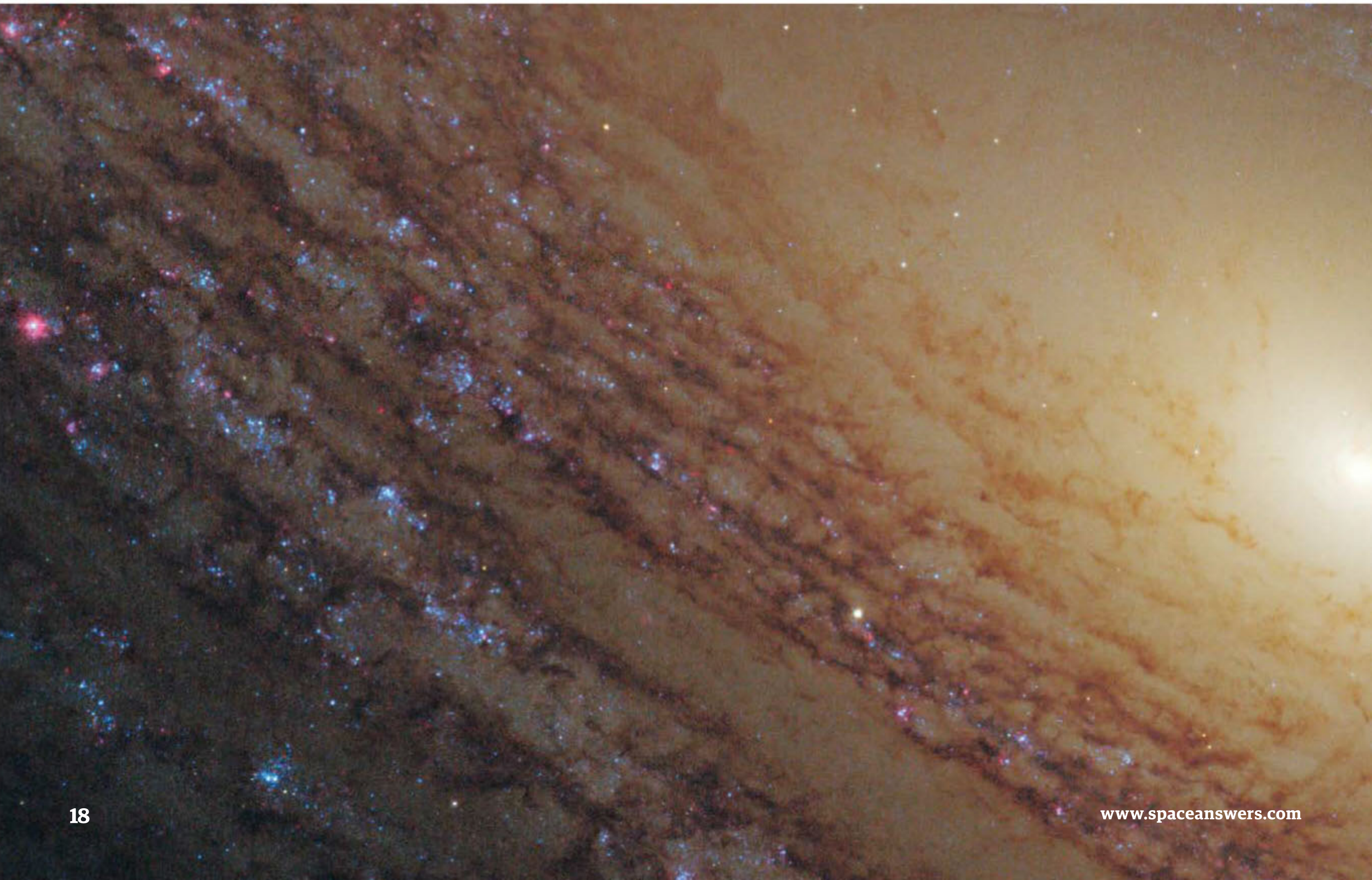


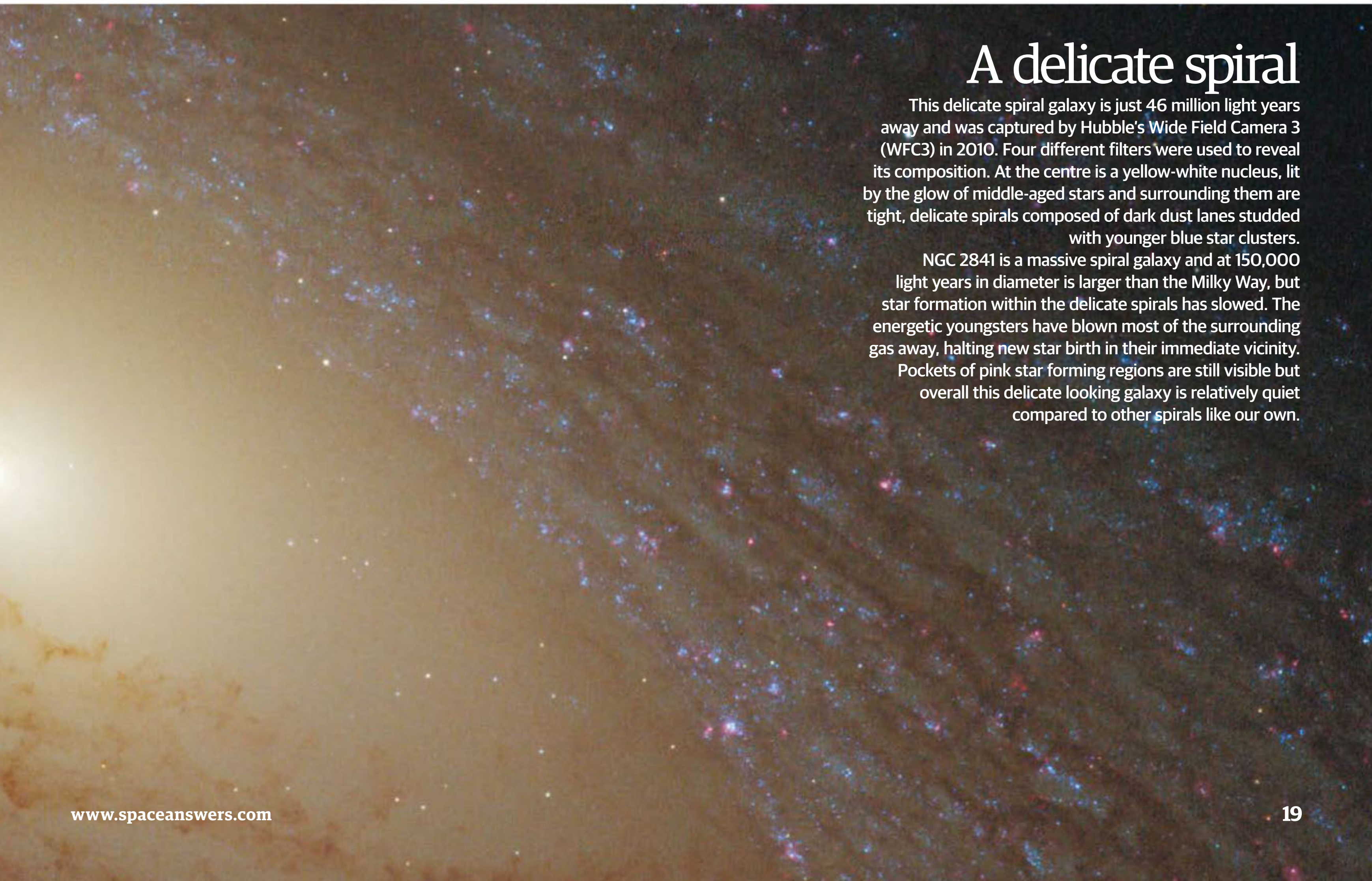
Hot new stars

This image, captured by the Advanced Camera for Surveys, shows a nebulous star forming in a region nestled inside the Small Magellanic Cloud, a dwarf galaxy 200,000 light years from Earth. At the centre are the hot young stars of the NGC 602 cluster. They are just five million years old and are still surrounded by the dust and gas from which they were formed, but their energetic outpourings have blown an enormous hole in the cloud. They are gradually eroding away at the gas, leaving behind vast pillars that point back inwards towards the source and in the turbulent environment amongst the ridges, more new stars are beginning to form, inching outwards as the cloud is gradually blown away. The incredible resolution of Hubble's camera also reveals background galaxies, including a face-on spiral just above this text.

The centre of the galaxy

In 2008, Hubble teamed up with the Spitzer Space Telescope to peer right into the centre of the Milky Way. In the process it orbited the Earth 144 times and made 2,304 separate exposures that were stitched together to build this stunning mosaic. Hubble's Near Infrared Camera and Multi-Object Spectrometer (NICMOS) were able to reveal objects around 20-times the size of our Solar System, producing the sharpest infrared image ever made of the core of the Milky Way. It revealed massive stars spewing strong stellar winds, sculpting the surrounding gas and showed the glow from ionised hydrogen in the vicinity. The image was laid over a colour survey, completed by the Infrared Array Camera on board the Spitzer Space Telescope, which although only about one tenth of the resolution of Hubble's image, separates the different wavelengths of infrared light by colour.

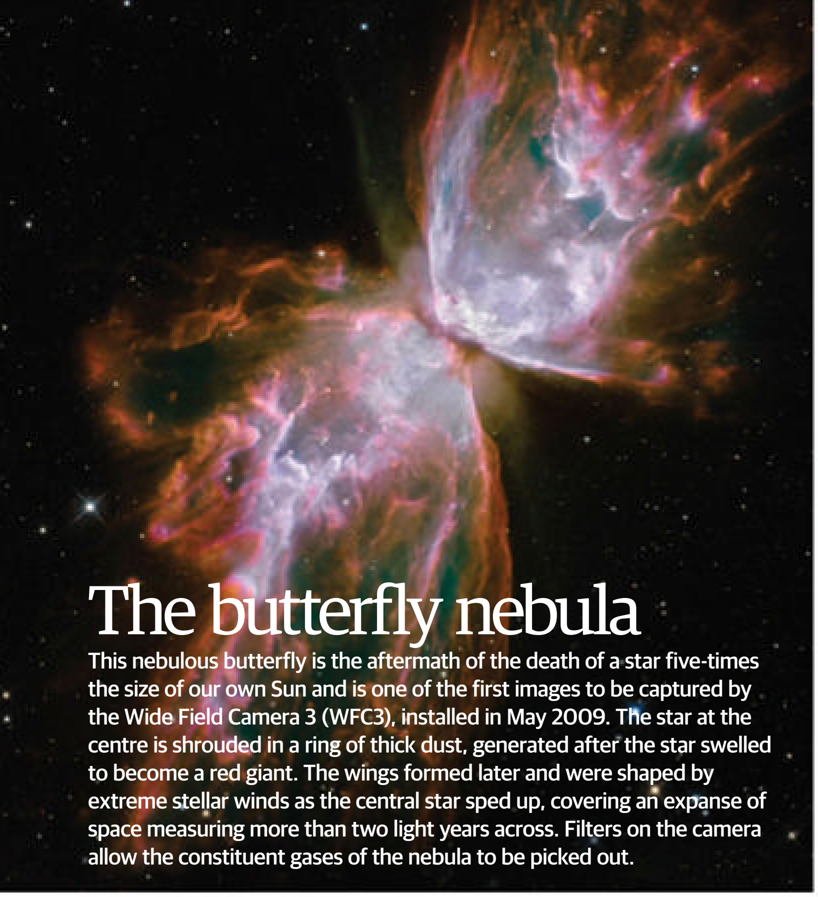




A delicate spiral

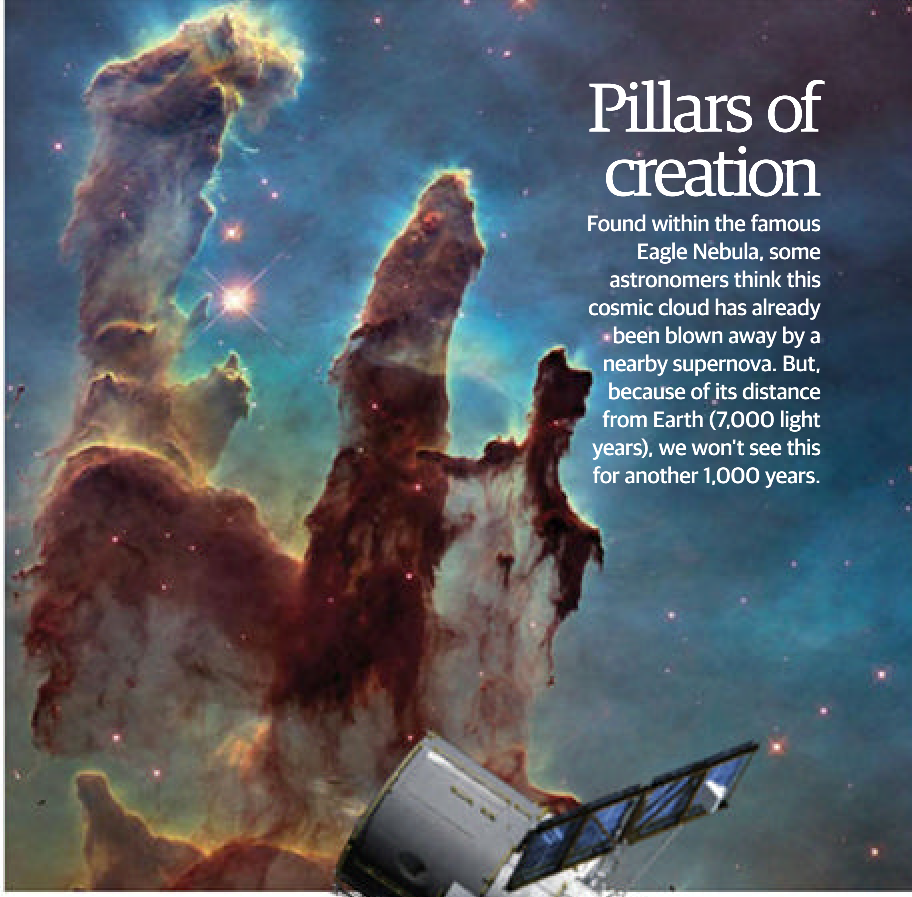
This delicate spiral galaxy is just 46 million light years away and was captured by Hubble's Wide Field Camera 3 (WFC3) in 2010. Four different filters were used to reveal its composition. At the centre is a yellow-white nucleus, lit by the glow of middle-aged stars and surrounding them are tight, delicate spirals composed of dark dust lanes studded with younger blue star clusters.

NGC 2841 is a massive spiral galaxy and at 150,000 light years in diameter is larger than the Milky Way, but star formation within the delicate spirals has slowed. The energetic youngsters have blown most of the surrounding gas away, halting new star birth in their immediate vicinity. Pockets of pink star forming regions are still visible but overall this delicate looking galaxy is relatively quiet compared to other spirals like our own.



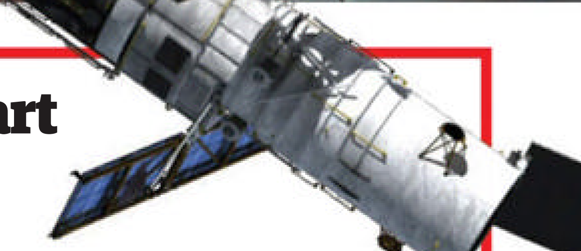
The butterfly nebula

This nebulous butterfly is the aftermath of the death of a star five-times the size of our own Sun and is one of the first images to be captured by the Wide Field Camera 3 (WFC3), installed in May 2009. The star at the centre is shrouded in a ring of thick dust, generated after the star swelled to become a red giant. The wings formed later and were shaped by extreme stellar winds as the central star sped up, covering an expanse of space measuring more than two light years across. Filters on the camera allow the constituent gases of the nebula to be picked out.



Pillars of creation

Found within the famous Eagle Nebula, some astronomers think this cosmic cloud has already been blown away by a nearby supernova. But, because of its distance from Earth (7,000 light years), we won't see this for another 1,000 years.



INTERVIEW

"I am certainly proud to have been a part of this fantastic scientific endeavour"

How did you get involved with Hubble?

"Shortly after its launch in 1990, I was contacted by a colleague that was already at the Space Telescope Science Institute (the institute that conducts the scientific program of Hubble) and he asked me whether I would consider coming to work at the Institute. I had visited it already in 1986 and hence was somewhat familiar with the organisation and I knew quite a few of the astronomers there. So after a brief hesitation, I said I would definitely consider it."

Hubble got off to a shaky start: what was the feeling at the Space Telescope Science Institute when the flaw was discovered?

"I was not yet at the Institute when the spherical aberration of the mirror was discovered, but I was absolutely shocked to hear about it. When I eventually decided to come to the Institute in 1991, a few of my colleagues were telling me that I must be crazy to come work with a flawed telescope. There was indeed a serious risk, since at that point we didn't know whether it could be corrected."

At the time, did you anticipate that Hubble would go on to be such a huge success?

"Absolutely not. At that time I feared that Hubble may be remembered as one of the biggest scientific failures. And one that could potentially jeopardise the entire concept of big, ambitious science. There was the danger that people would use the Hubble example to argue that too complex scientific missions are doomed to fail."

How did the mood change after it was fixed?

"One can hardly describe it. The feeling of elation was similar perhaps to that felt after the birth of a new child. The drama added, of course, to the iconic status of this telescope. This was an amazing demonstration of what can be achieved through the ingenuity of scientists and engineers and the courage of astronauts."

What do you think is the most iconic image captured by Hubble and which one is your personal favourite?

"There is little doubt that the Eagle Nebula is Hubble's most iconic image. We have re-observed that region this year in high definition as part of the 25th anniversary celebrations. The new image is breathtaking. I personally like very much the image we call 'Mystic Mountain', which also shows pillars of gas and dust in which new stars are being born."

What were you hoping to see in the Hubble Deep Field images?

"The various Hubble Deep Fields have not only shown us the universe at its infancy, when it was less that 500 million years old, while its current age is 13.8 billion years, they have also given us the cosmic history. For instance, we now know the rate at which the universe as a whole has been forming new stars, throughout its entire history. By showing us thousands of galaxies in an area of the sky similar to that you would see through a drinking straw, the Deep Fields have visually demonstrated to us the smallness of our physical existence, compared to the vastness of space. No one knew exactly what to expect from the Deep Fields, but they turned out to be a demonstration of cosmic archaeology at its best. "

What is it about Hubble that has captured the public imagination?

"A few elements have combined to make Hubble almost unique in the history of science. Hubble has brought the excitement of discovery, which used to be the province of only scientists, into the homes of people all across the globe. The drama that was associated with the flaw in the mirror and its spectacular repair has also added to Hubble's popularity - this was the 'telescope that could'. The incredible servicing missions by shuttle astronauts also captured the imagination. Hubble's longevity, 25 years of outstanding scientific results and the unbelievable images, some of which have been dubbed by an art writer as "the most remarkable works of art of our time."

What does the future look like for Hubble?

"We hope very much that Hubble will continue to operate at least till 2020, which will allow it a few years of overlap with the James Webb Space Telescope. If the telescope will still be scientifically productive at 2020, I hope that it will be kept even beyond that. Eventually, a propulsion module will be attached to the telescope, directing it into the ocean. However, I am convinced that Hubble will still make important discoveries in the coming years. I am certainly proud to have been a part of this fantastic scientific endeavour."

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Hubble - 25 Years of Space Exploration

Celebrating 25 years since its launch, eight stamps feature spectacular images from the Hubble Space Telescope. The Miniature Sheet features the Hubble in its final release over Earth.

Images courtesy of www.hubblesite.org NASA and STScI

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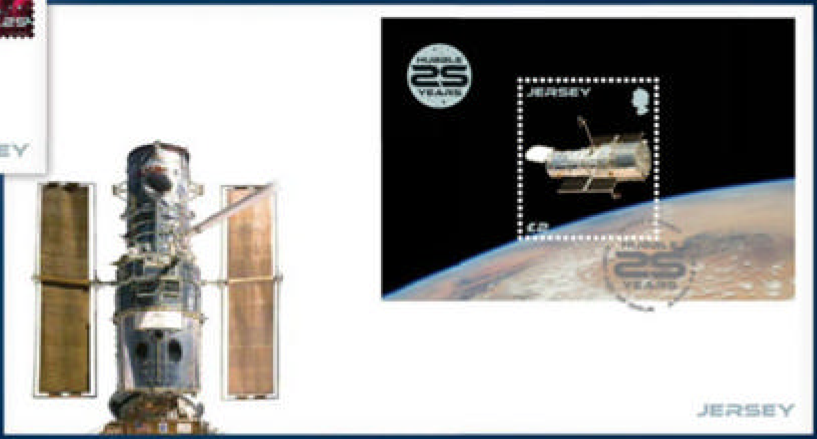

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YOUR FIRST CONTACT WITH THE UNIVERSE

Mars had a sea bigger than the Arctic Ocean

A new study from a team at NASA suggests the Red Planet has lost a staggering 85 per cent of its water

Don't let its barren and arid landscape fool you, Mars could well have been a very different place 4.3 billion years ago. According to new research conducted by scientists at the Goddard Space Flight Centre in Maryland, the Red Planet was home to an ocean so big it would have dwarfed our own Arctic Ocean.

Using ground-based observatories, such as the European Southern Observatory's Very Large Telescope and the WM Keck Observatory and NASA Infrared Telescope Facility in Hawaii, scientists have been studying the water signatures in the planet's atmosphere. It has long been theorised that Mars lost most of its water to space due to atmospheric changes, but few have been able to determine how much water resided there before its expulsion.

"Our study provides a solid estimate of how much water Mars once had, by determining how much water was lost to space," said Geronimo Villanueva, a scientist at Goddard Space Flight Center. "With this work, we can better understand the history of water on Mars."

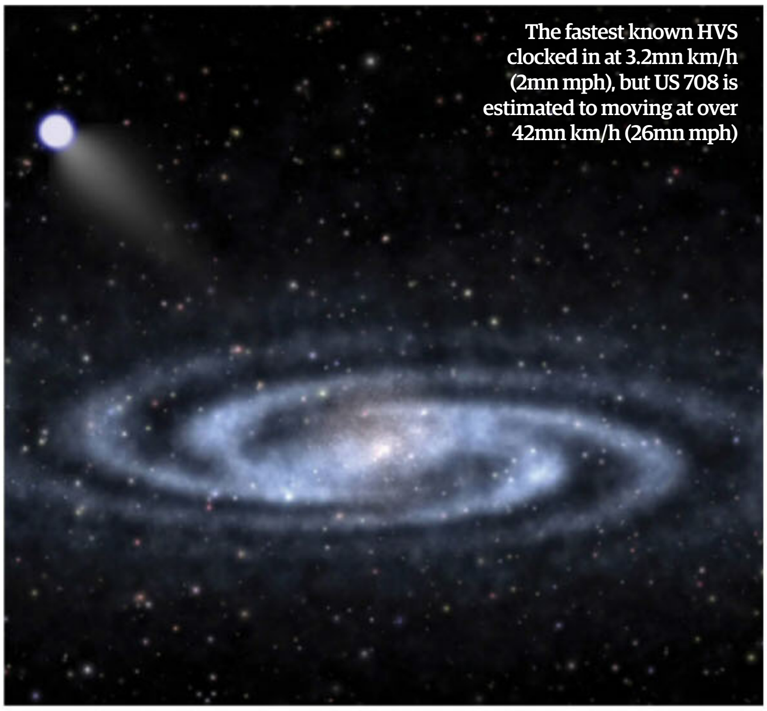
> "The ancient ocean would have covered almost half of Mars' northern hemisphere, with potential depths of up to 1.6km (1mi)"

According to the paper, that history suggests Mars was a much more varied environment billions of years ago. Around 4.3 billion years ago to be exact, it would have had enough natural water to cover its entire surface at a depth of 137 metres (450 feet). In reality, that water would have formed a huge ocean that covered almost half of Mars's northern hemisphere with potential depths of up to 1.6 kilometres (one mile).

The paper also raises the interesting question of where in the martian northern hemisphere this ancient ocean would have been found. Based on the surface of Mars, the most likely geographical candidate is the Northern Plains, mainly due to its low-lying topography. In this location, a martian ocean would have covered a huge 19 per cent of the planet's surface. To put it in context, the Atlantic Ocean covers 17 per cent of Earth's surface.

"With Mars losing that much water, the planet was very likely wet for a longer period of time than was previously thought, suggesting it might have been habitable for longer," said Michael Mumma, co-author on the paper.

The research studied the atmosphere of Mars, comparing the ratio between H2O and HDO, a variation of H2O that replaces one hydrogen with the heavier deuterium. By comparing this data to the ratio found in a martian meteorite, the team can determine the atmospheric changes that caused the ocean to evaporate and how much was lost to space. ■



The fastest known HVS clocked in at 3.2mn km/h (2mn mph), but US 708 is estimated to moving at over 42mn km/h (26mn mph)

Fastest star in our galaxy gets thermonuclear acceleration

A speedy stellar body is leaving the Milky Way, thanks to a supernova

When a star is moving through our humble galaxy at 745 miles (1,200 kilometres) per second, it's rather hard to ignore. The burning ball of super-heated gas in question, US 708, is currently on a course that will send it hurtling out of our corner of the universe, but the origin of that departure isn't quite what you might be expecting.

When it comes to any star moving at such a speed, many scientists would normally assume the culprit to be the supermassive black hole

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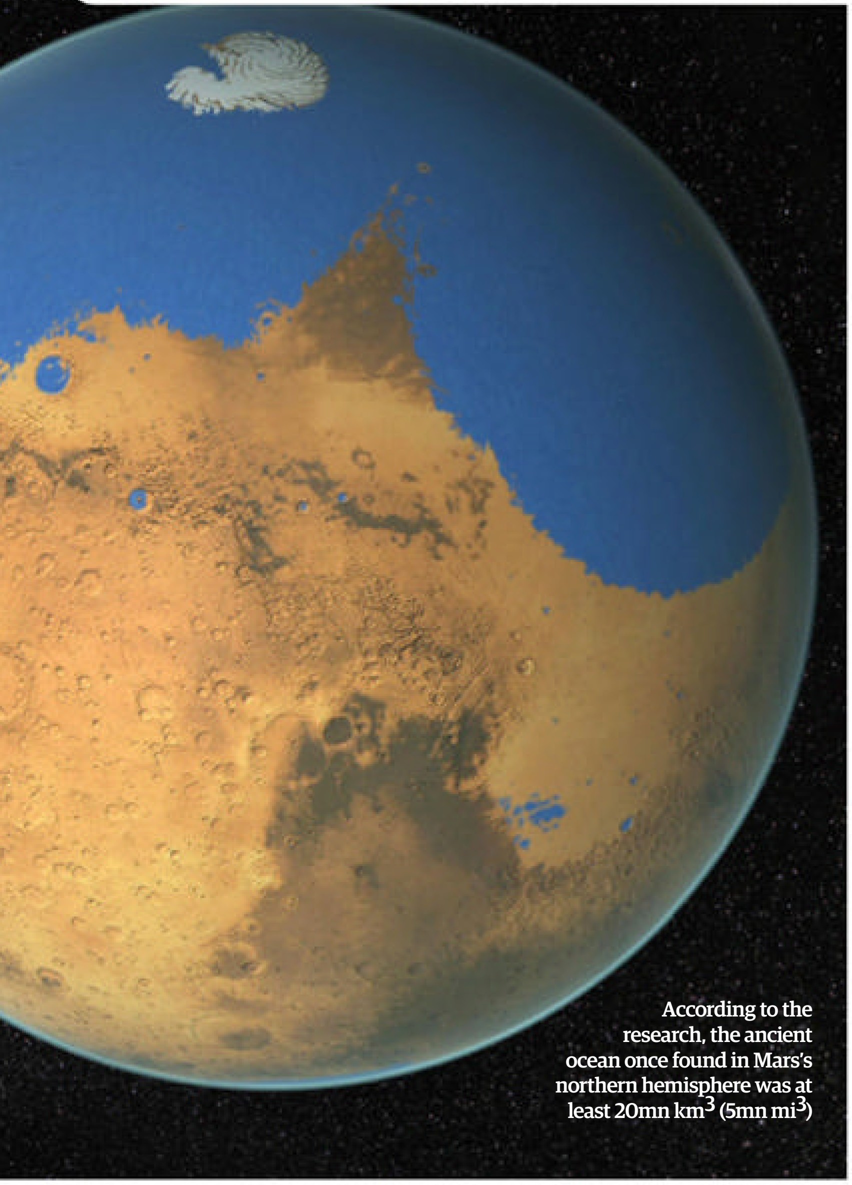

According to the research, the ancient ocean once found in Mars's northern hemisphere was at least 20mn km^3 (5mn mi^3)

at our galaxy's centre, but according to a new research paper published in the journal *Science*, the cause of such an ejection was more than likely produced by the death of another nearby star. The resulting supernova expelled US 708 on a crash course out of the Milky Way.

Most of the stars in our galaxy are bound to a gravitational setting, such as our own Sun, but some are free and roving through space. Those moving at a speed faster than 1,000 kilometres (621 miles) per second are known as hypervelocity stars (HVS), including the ultra-fast US 708.

"In reconstructing its trajectory, the galactic centre becomes very unlikely as an origin, which is hardly consistent with the most favoured ejection mechanism for the other HVSs," reads the paper. The research states that US 708 doesn't share the same characteristics as a HVS that's been slingshotted by a black hole but rather it shows a rotating motion commonly caused by the, "donor remnant of a thermonuclear supernova." ●

"Many scientists would normally assume the culprit to be the supermassive black hole"

The Rosetta probe's shadow is photographed by its on-board camera as it appears on the surface of comet 67P, following a low pass

Rosetta probe catches its own shadow

As of part of its Valentine's Day flyby in February, the Rosetta probe snapped some brand new images from Comet 67P/Churyumov-Gerasimenko. In fact, the probe flew so low, six kilometres (3.7 miles) from the surface to be precise, that it managed to catch a shot of its own shadow from the surface of the icy rock.

The image above, taken with Rosetta's on-board OSIRIS imaging system, was not only the closest the probe has ever come to the comet, but shows off a truly unique set of conditions. For a short time during the flyby manoeuvre, the Sun, the craft and the comet were perfectly aligned.

"Images taken from this viewpoint are of high scientific value", said OSIRIS principal investigator Holger Sierks from the Max Planck Institute for Solar System Research (MPS) in Germany. Since the contours of the comet's surface cast almost no shadows, such an alignment enables scientists to study the minute aberrations of its topography. "This kind of view is key for the study of grain sizes", he adds. ●

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ISS announces new crew

NASA, the European Space Agency (ESA), the Russian Federal Space Agency (Roscosmos) and the Japan Aerospace Exploration Agency (JAXA) have revealed the three crews taking part in Expeditions 48, 49 and 50. These missions will begin next year.

Hungary and Estonia become ESA Member States

In February 2015, Estonia and Hungary signed the ESA Convention, becoming the 21st and 22nd countries to have signed the Accession Agreement.

NASA launches fifth Earth-science satellite

Scientists at NASA are celebrating the agency's busiest year for more than a decade after the launch of its fifth Earth-orbiting satellite in the last 12 months.

ESA greenlights Biomass satellite program

The ESA's Biomass initiative will aim to study the status and dynamics of the Earth's tropical rainforests, with a planned launch date of 2020.

LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

After more than seven years of travel and study elsewhere, scientists at NASA and space agencies around the world can't wait to find out more about the history of Ceres

Dawn orbits our biggest unexplored world

Nearly eight long and eventful years after its dual-mission launch, NASA's Dawn spacecraft has finally surpassed a truly incredible landmark by becoming the first ever spacecraft to orbit around the icy dwarf planet Ceres, the biggest unexplored planetary body in our inner Solar System.

Dawn entered the gravitational pull of the dwarf planet at 4.39am PST on 6 March at a distance of around 61,000 kilometres (38,000 miles), with the extremely excited team at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, receiving a confirmation signal roughly an hour later.

"Since its discovery in 1801, Ceres was known as a planet, then an asteroid and later a dwarf planet," commented Doctor Marc Rayman, Dawn chief engineer and mission director at JPL. "Now, after an incredible journey of 4.9 billion kilometres (3.1 billion miles) and 7.5 long years, Dawn can finally call Ceres home."

In fact, its orbit of Ceres isn't the only first for the seasoned Dawn spacecraft. Between 2011 and 2012, it explored the giant, rocky asteroid Vesta as part of its dual mission, giving Dawn the distinction of being the only spacecraft in history to have visited the two most massive objects in our Solar System's asteroid belt. ●

Over 200 galaxy clusters have been studied by the Chandra Observatory, including Abell 2597 seen here, in a hope of further understanding the effects of black holes on the galaxy

Cosmic showers are slowing galaxy growth

Through the Chandra X-ray Observatory, NASA astronomers have found that galaxies with supermassive black holes can find their growth and expansion hampered by a rather unique phenomenon known as cosmic precipitation.

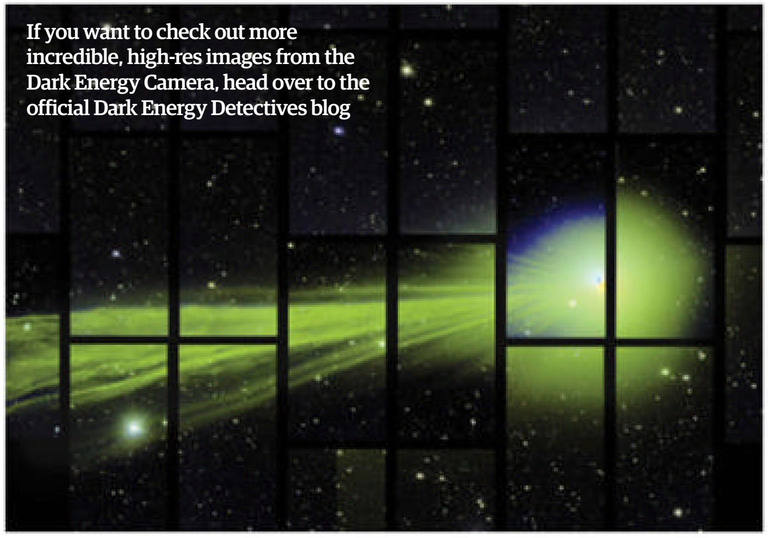
Clouds of hot cosmic gas usually cool over time, providing the optimum conditions for the formation of new stars, however, scientists now believe this presence of black holes directly affects this cycle. Cool gas drawn into a black hole can trigger energetic jets of particles, which cause the cool gas to reheat, thus hindering the star birth process. This cycle of heating and cooling creates a feedback loop that they believe directly affects the growth of a galaxy.

"We know that precipitation can slow us down on our way to work," said Mark Voit of Michigan State University (MSU), USA, lead author of the paper on cosmic precipitation. "Now we have evidence it can also slow down star formation in galaxies with huge black holes." Voit and his team have studied more than 200 galaxy clusters and their research brings astronomers closer to understanding the influence black holes have on the surrounding galaxy.

A joint effort by NASA and ESA has given a glimpse at these powerful, galaxy-affecting winds in action. The images, captured through NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) and ESA's XMM-Newton telescope show black holes firing out ultra-fast winds containing ionised atoms. ●

Comet Lovejoy caught on super camera

"Accidental observation" captures amazing images of this celestial body



If you want to check out more incredible, high-res images from the Dark Energy Camera, head over to the official Dark Energy Detectives blog

Using the world's most powerful imaging equipment - the Dark Energy Camera based at the Cerro Tololo Inter-American Observatory in Chile - scientists have captured a series of incredible images that show Comet Lovejoy as it passed by at a distance of 82 million kilometres (51 million miles) from Earth.

The camera, which can image up to 8 billion light years away with its 570-million megapixel lens, was studying the southern sky as part of its five-year mission to analyse the presence and effect of dark energy, a mysterious form of energy that some astronomers believe permeates throughout the entire universe and happened upon the passing comet by pure chance.

"Our favourite [memory] of all was the accidental observation of Comet Lovejoy," wrote the blog Dark Energy Detectives (a blog of the Dark Energy Survey) of the sighting. "It reminds us that before we can look out beyond our own galaxy to the far reaches of the universe, we need to watch out for celestial objects that are much closer to home."

The image shows the massive ball of ice, approximately 4.8 kilometres (three miles) across at the centre of the comet, as well as a highly visible cloud of gas and dust at its bright head, roughly 643,740 kilometres (400,000 miles) in diameter. ●

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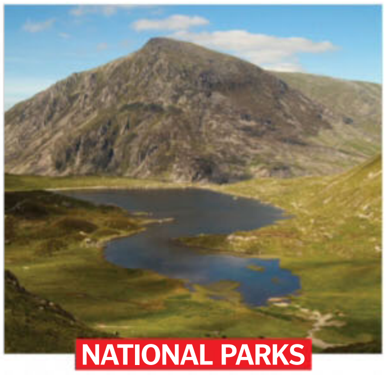
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CERES
The missing planet

For 214 years, dwarf planet Ceres has remained tantalisingly close but it has never been visited - until now. **All About Space** follows NASA's Dawn spacecraft as it reaches the second stage of its ambitious mission

Written by David Crookes

Imagine there was a sizeable body in the Solar System, one closer to Earth than Jupiter, Saturn, Uranus and Neptune. Imagine it had water and even the possibility, no matter how slight, of alien life. Imagine it could hold clues to the origins of the Solar System and tell us more about the formation of our own planet.

That body is Ceres, an alien world named after the Roman goddess of agriculture, which exists in the asteroid belt between the orbits of Mars and Jupiter. It was discovered on 1 January 1801 by a Sicilian Catholic priest, mathematician and astronomer called Giuseppe Piazzi who initially thought Ceres was a comet, albeit one with no nebulosity or tail.

Deep down, he believed his finding may have been something better, a hunch he confided to two astronomers in Milan and Berlin later that month. Although there have been subsequent observations and Ceres has continued to fascinate astronomers, in the 214 years that have since passed, Ceres has taken the dubious honour of being the largest body between the Sun and Pluto never to have been visited by a spacecraft.

Until now that is. In 2007 NASA launched a probe into space to target Vesta and Ceres, the two most massive residents of the asteroid belt. The Dawn Mission has already seen the spacecraft orbit Vesta, the brightest asteroid visible from Earth. Since then it has been en route to Ceres, finally reaching its destination in March 2015. In doing so, Dawn is allowing astronomers to unlock the dwarf planet's secrets for the first time.

"The area between Mars and Jupiter has been under-explored," says Marc Rayman, chief engineer and mission director of the Dawn Mission. "But that is because when humankind began exploring space the objectives were to go to the easy destinations and the asteroid belt was seen as very difficult to reach. Mars and Venus were the obvious places to go and so they became the early targets of a great number of space missions. It's not surprising that scientists would want to go to the objects that have been relatively well-studied and Venus, Mars, Jupiter, Saturn and so on have been the subjects of extensive investigation."

Dawn is what is called a multi-target mission and its aim from the start was to visit the two largest bodies in the asteroid belt. These proto-planets would most likely have grown into adult bodies had Jupiter's gravitational force not been so strong that it interrupted the process, dating back some 4.5 billion years to the very beginnings of the Solar System. Studying these celestial bodies will therefore give astronomers a great window into the past. What's more, given that Ceres accounts for around 30 per cent of the mass of the asteroid belt and Vesta is eight per cent, Dawn is able to explore almost 40 per cent of the total mass of this region of space.

By visiting both within the same mission in what is the first time a probe has ever orbited two Solar System targets, NASA is able to carry out comparative planetology. Already Vesta has been found to be rocky and mostly dry, resembling the terrestrial planets of Mercury, Venus, Earth and Mars as well as the Moon. To that degree, it's the outermost of the terrestrial-type planets. Ceres is just a little bit further from the Sun and more closely resembles the icy moons of the outer Solar System, the moons of Jupiter and Saturn.

"It's almost as if these two bodies straddle what some astronomers call a dew-line, or a snow line, or a frost-line in the Solar System," explains Doctor Rayman. "So being able not only to study each body but also to compare them and try to understand why they are so different, even though they are relatively close to each other, presents an opportunity to learn more about the nature of the Solar System. This mission also lets us orbit two destinations in one mission, with the capabilities provided by technology letting us get two worlds for the price of one. That provides a better scientific return for the investment that the United States tax payers have made in NASA. Also, I think it's a lot cooler."

Most of our knowledge of Ceres, the only dwarf planet located in the inner reaches of the Solar System, has up to this point been gained through the lens of the Hubble Space Telescope. It has given astronomers a good idea of a body that has an equatorial diameter of around 975 kilometres (606 miles) and a land area roughly equivalent to a third of Europe. It has been observed to have a primitive surface and it is thought to have a weak atmosphere. NASA also says microwave studies have suggested Ceres is covered with a dry clay (as opposed to a basaltic dust layer on Vesta) and that its thick ice mantle may be hiding an ocean.

There have been other observations. In January 2014, scientists using the European Space Agency's Herschel Space Observatory made the first definitive detection of water vapour on the dwarf planet. NASA had suspected that this had been the case for a while based on Hubble findings and it was delighted to see its theory confirmed. Michael Küppers, lead author of a paper in the journal *Nature* said it was proof Ceres had an icy surface and an atmosphere that astronomers working on Dawn are naturally keen to explore in further detail.

"We have been able to estimate the mass of Ceres according to how much it perturbs the orbits of smaller bodies in the asteroid belt," says Doctor Rayman. "Knowing the shape and mass from Hubble, we have been able to estimate Ceres' density which we have found to be quite low, only a little bit more than two grams (0.07 ounces) per cubic centimetre [0.06 cubic inches]. Based on that, plus evidence from Herschel, we can determine that Ceres likely has a substantial amount of water residing in it."

Density is a good indicator of water. Earth has a density of 5.5 grams (0.19 ounces) per cubic centimetre and Vesta, as Dawn found, has a density of about 3.5 grams (0.12 ounces) per cubic centimetre, which puts it in line with the other terrestrial-type planetary bodies. "Ceres having such a lower density is more easily explained by the presence of water," adds Rayman. "The inventory of water is most likely in the form of ice but mathematical models show that Ceres may have enough heat in it from the combination of radioactive materials that it would have incorporated when it formed.

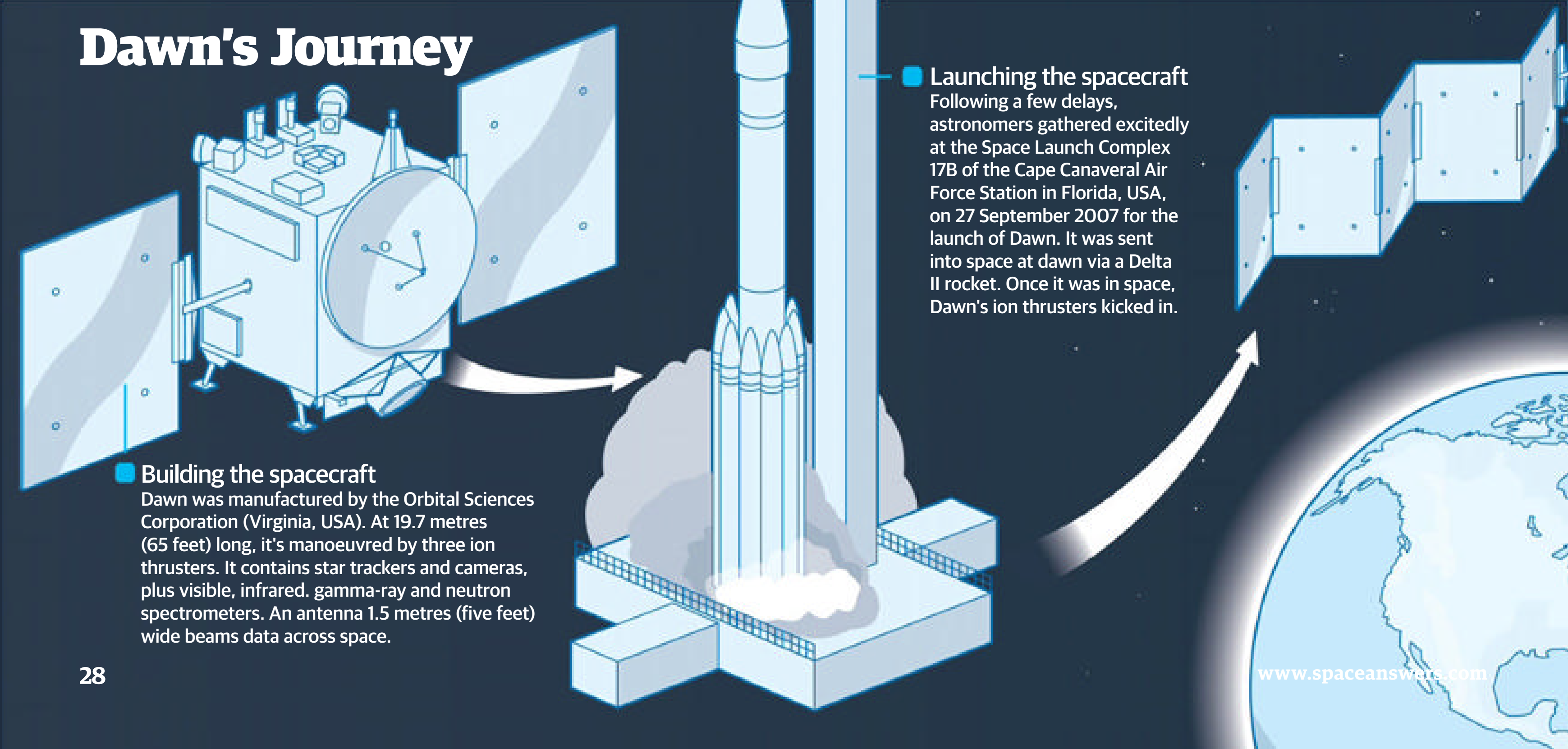
"When you add the faint, but nonetheless persistent sunlight Ceres has received, it's likely that some water could be liquid, so there may be subsurface oceans. I would like to emphasise that while Hershel observed water vapour above Ceres, it was a very tiny amount. The density of the water vapour is much less than that of the atmosphere where the International Space Station orbits."

So could Ceres support life? Doctor Rayman says the possibility is "exceedingly unlikely" and adds that if there was, "it would have to be beneath the surface and Dawn will not have the capability to detect it". Even so, it may still be that astronomers observe chemistry and other conditions that are important or at least inform them of the conditions which led to the development of life on other planets like Earth.

Dawn first had Ceres in its sights and began taking images in December 2014. A few weeks later, a white spot was noticed, which astronomers suggested could be a frozen pool of ice reflecting light from the bottom of a crater. Images taken on 4 February 2015 from a distance of 145,000 kilometres (90,100 miles) proved more tantalising still. In the south polar region it was possible to see a sizeable, circular impact crater. It is making fresh, exciting discoveries and confirming theories. "We have known with a reasonable idea what Ceres' shape and size is, that its shape is close enough to spherical that it satisfies the criteria of being a dwarf planet," says Doctor Rayman. Yet Ceres' status has not always been so certain. When Piazzi discovered Ceres, it was deemed to be the eighth planet of the Solar System. Within six years, German astronomer Heinrich Wilhelm Olbers had discovered Vesta and Pallas. They were hugely significant finds and they proved the hunch that

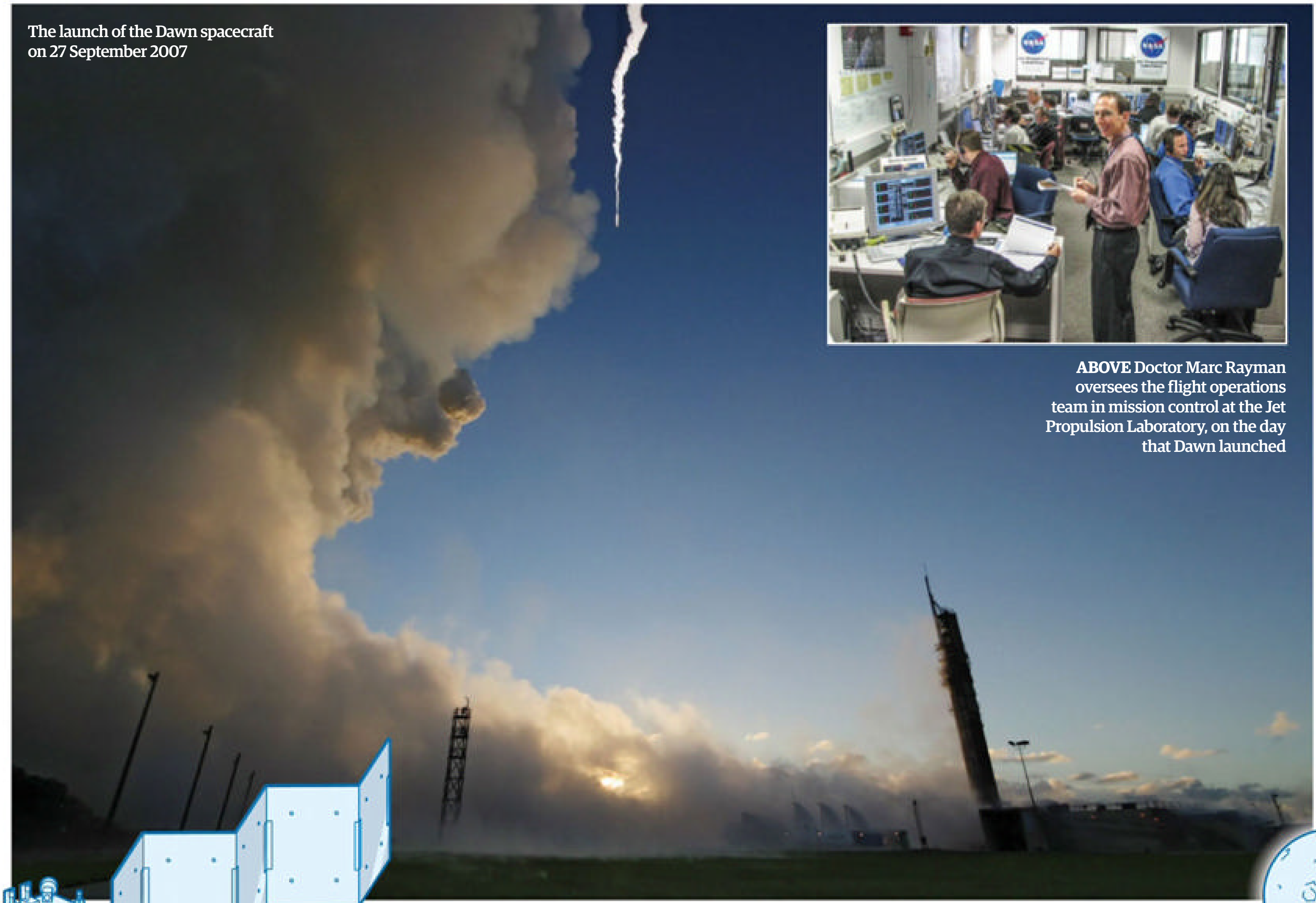
> "Studies have suggested Ceres may be hiding an ocean"
>
> **Doctor Marc Rayman**

Dawn's Journey



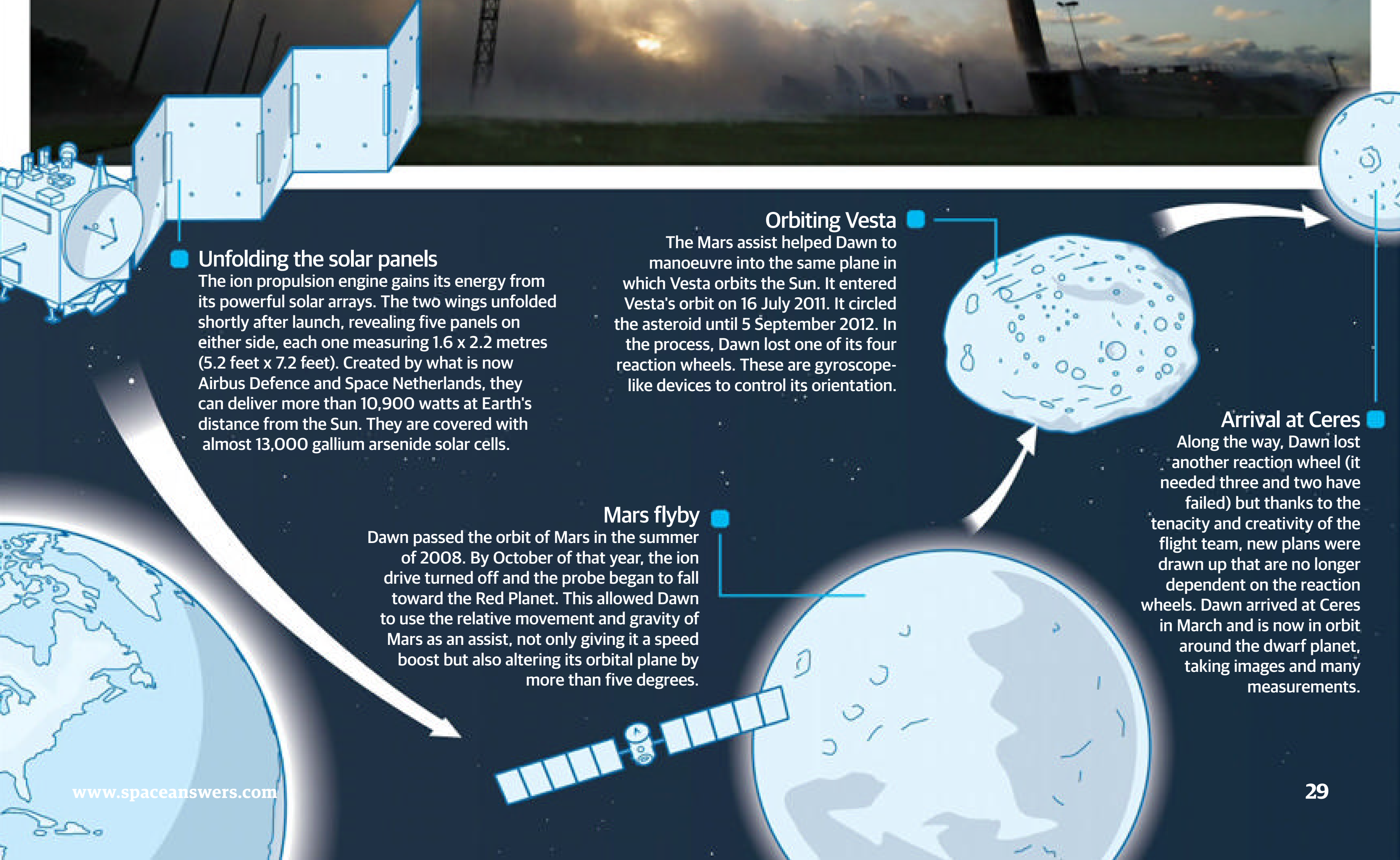
Building the spacecraft
Dawn was manufactured by the Orbital Sciences Corporation (Virginia, USA). At 19.7 metres (65 feet) long, it's manoeuvred by three ion thrusters. It contains star trackers and cameras, plus visible, infrared. gamma-ray and neutron spectrometers. An antenna 1.5 metres (five feet) wide beams data across space.

Launching the spacecraft
Following a few delays, astronomers gathered excitedly at the Space Launch Complex 17B of the Cape Canaveral Air Force Station in Florida, USA, on 27 September 2007 for the launch of Dawn. It was sent into space at dawn via a Delta II rocket. Once it was in space, Dawn's ion thrusters kicked in.



The launch of the Dawn spacecraft on 27 September 2007

ABOVE Doctor Marc Rayman oversees the flight operations team in mission control at the Jet Propulsion Laboratory, on the day that Dawn launched



Unfolding the solar panels

The ion propulsion engine gains its energy from its powerful solar arrays. The two wings unfolded shortly after launch, revealing five panels on either side, each one measuring 1.6 x 2.2 metres (5.2 feet x 7.2 feet). Created by what is now Airbus Defence and Space Netherlands, they can deliver more than 10,900 watts at Earth's distance from the Sun. They are covered with almost 13,000 gallium arsenide solar cells.

Mars flyby

Dawn passed the orbit of Mars in the summer of 2008. By October of that year, the ion drive turned off and the probe began to fall toward the Red Planet. This allowed Dawn to use the relative movement and gravity of Mars as an assist, not only giving it a speed boost but also altering its orbital plane by more than five degrees.

Orbiting Vesta

The Mars assist helped Dawn to manoeuvre into the same plane in which Vesta orbits the Sun. It entered Vesta's orbit on 16 July 2011. It circled the asteroid until 5 September 2012. In the process, Dawn lost one of its four reaction wheels. These are gyroscope-like devices to control its orientation.

Arrival at Ceres

Along the way, Dawn lost another reaction wheel (it needed three and two have failed) but thanks to the tenacity and creativity of the flight team, new plans were drawn up that are no longer dependent on the reaction wheels. Dawn arrived at Ceres in March and is now in orbit around the dwarf planet, taking images and many measurements.

there were bodies in the gaping gap that lay between Jupiter and Mars.

As time went on, however, these three discoveries were downgraded from planet status to asteroids. Only in 2006 was Ceres given a boost, having been re-classified as a dwarf planet, the same label bestowed on Pluto in the same year. "Ceres was the first dwarf planet discovered and so it will be, appropriately, the first one that humankind will explore" adds Doctor Rayman, who also has little sympathy for former planet Pluto, a dwarf planet that will incidentally receive a fly-by from NASA's New Horizons spacecraft in July.

"It's interesting that there are many people who are still distressed about the change in status of Pluto," he jokes. "How could Earth be so inconsiderate, why didn't we think of Pluto's feelings in the matter and what kind of planetary bully are we?" But this kind of reassessment is necessary, since it reflects our increasing understanding of the nature of the universe. With the advance of scientific knowledge comes a change in vocabulary. "I think that the capability to send spacecraft to a distant, alien, mysterious, exotic world and explore it and learn what secrets it holds is fascinating," he continues. "We want to know the truth and I think it's really exciting that we now have a spacecraft that is revealing many exciting new secrets."

A few decades ago, travel to Vesta and Ceres would have been nearly impossible. Not only were astronomers more interested in targeting Mars and Venus but it was also widely acknowledged that the asteroid belt was harder to explore. "When we send a spacecraft into orbit around a distant planet, the gravity of that planet helps pull the spacecraft into orbit but the objects in the main asteroid belt don't have as much gravity which makes it more difficult" says Doctor Rayman.

Before Dawn, the typical way of making a preliminary visit to a large body was a fly-by, which eliminates the tricky need to enter a planet's orbit. But had a fly-by taken place during a mission to Vesta and Ceres, it would have gathered too little information since these bodies are too small for such a spacecraft to pick up enough detail. The only way of making this kind of mission worthwhile is to get in close and stay there for a long time. "And we had to wait until we had the more advanced capability provided by ion propulsion," says Doctor Rayman.

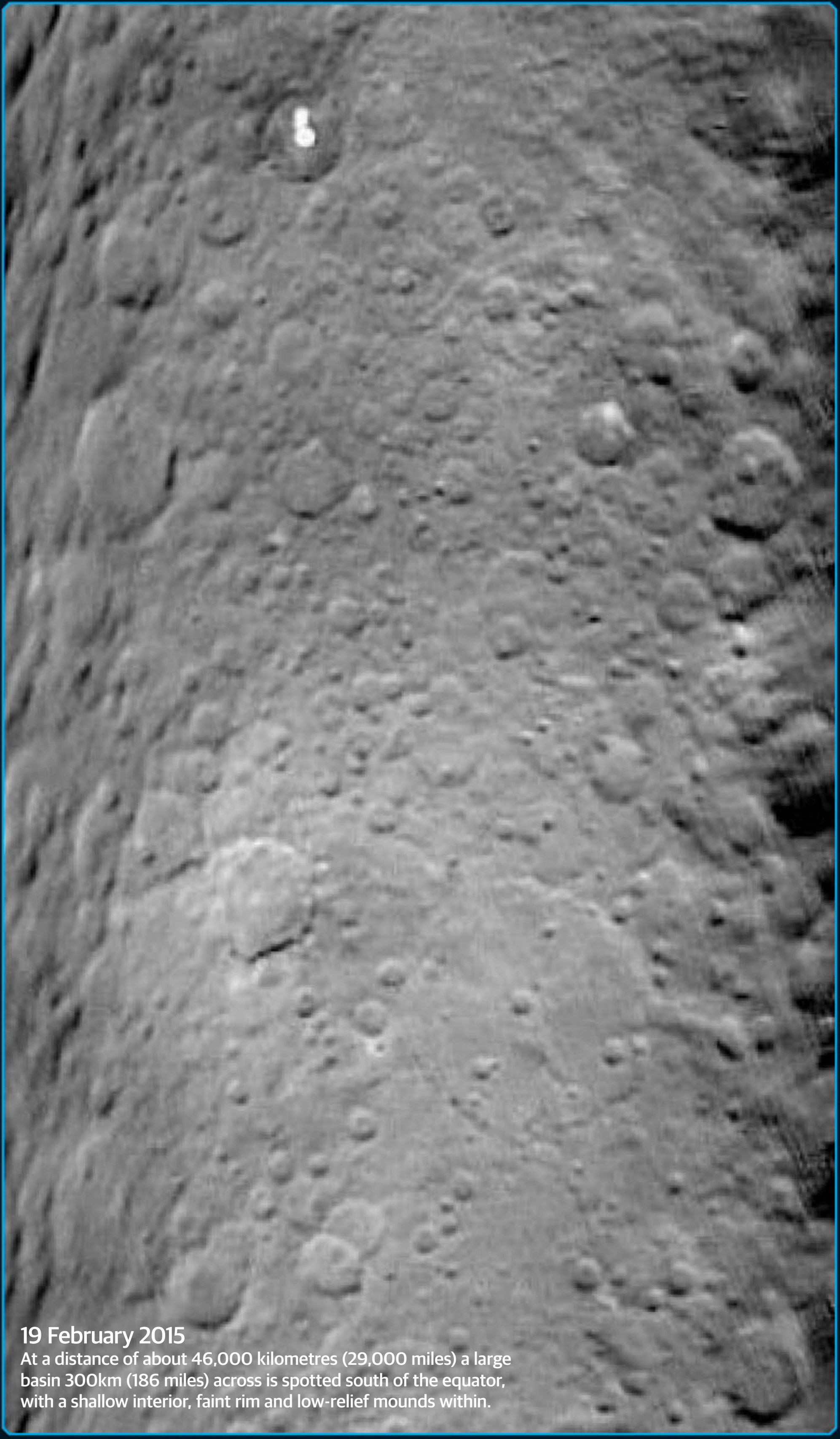
The ion propulsion engine has been critical in making the Dawn Mission to Vesta and Ceres possible. It was a novel concept and one that Professor Christopher Russell seized upon with open arms. He recalls an engineer discussing the possibilities of space exploration using ion engines and Professor Russell saw it as a great opportunity for a future visit to the asteroid belt.

His team's initial proposals failed and so did a good few subsequent ones, since the ion engine had not been as refined as NASA had hoped. That changed when Deep Space 1 became the first interplanetary spacecraft to use ion propulsion as the primary propulsion system in 1998.

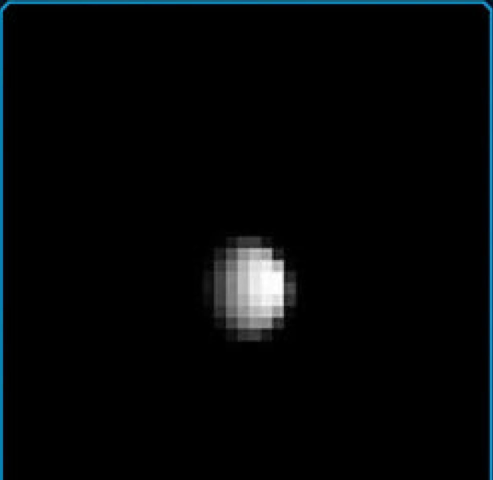
Ion propulsion makes efficient use of fuel and electrical power and it has emerged as a better alternative to chemical propulsion. Thrusters electrically charge a gas called xenon and then expel

Dawn's approach

On 6 March 2015, Dawn became the first spacecraft to achieve orbit around a dwarf planet. Here are several key points in its journey



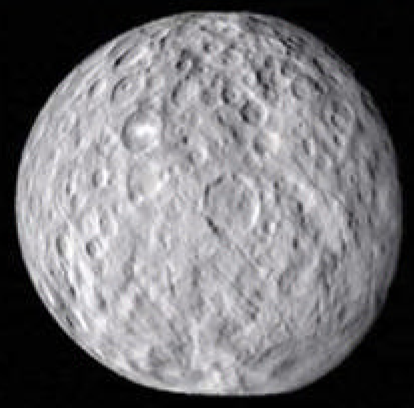
19 February 2015
At a distance of about 46,000 kilometres (29,000 miles) a large basin 300km (186 miles) across is spotted south of the equator, with a shallow interior, faint rim and low-relief mounds within.



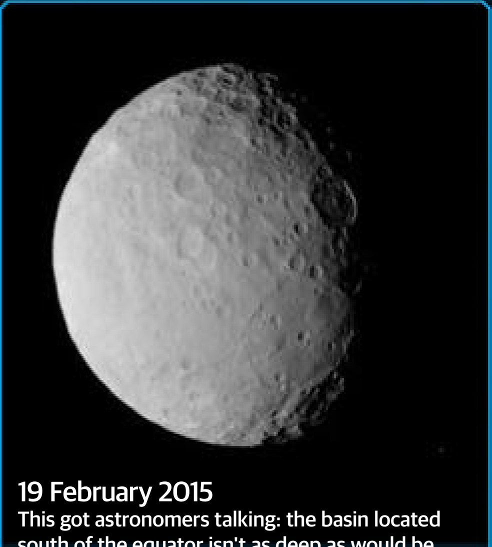
1 December 2014
At 1.2mn km (740,000mi) from Ceres, Dawn is almost there. This is a nine-pixel-wide photo it took using its framing camera.

13 January 2015
The Dawn team processed the image from 383,000km (237,985mi). At this point, it looks like there are craters on the surface on Ceres.

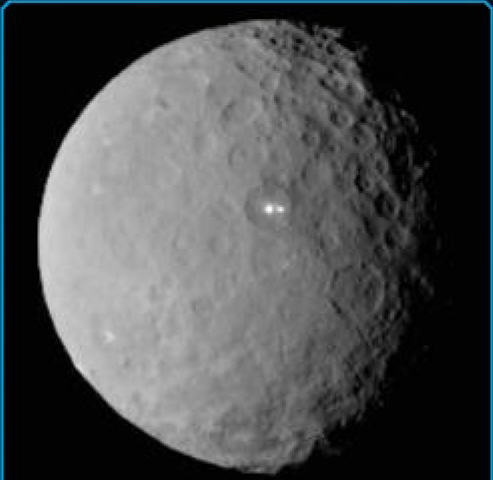
13 January 2015
Still 383,000km (237,985mi) away, but scientists are intrigued by the mysterious bright white spot on Ceres. They think it may contain a lot of ice.



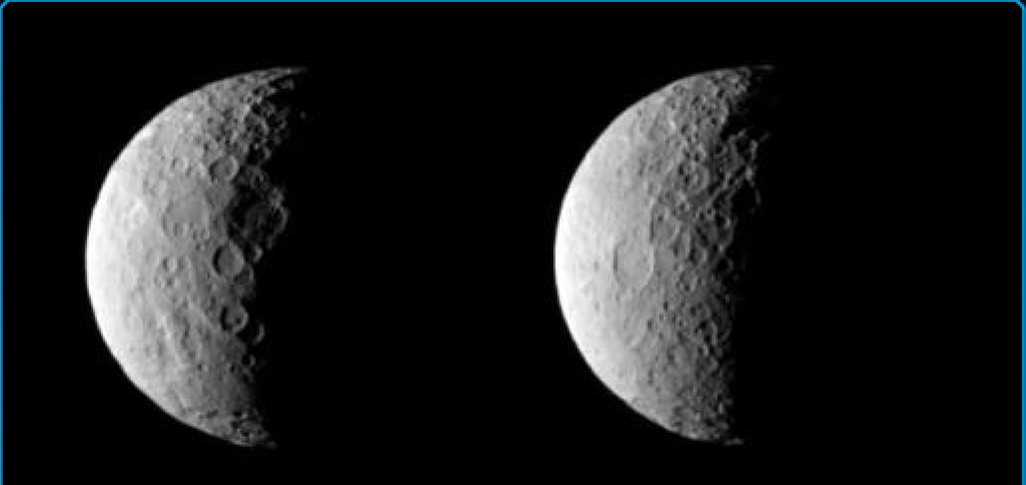
19 February 2015
At 46,000km (28,583mi). North of the equator you can see two bright spots in a single crater. Scientists don't know its true brightness yet though.



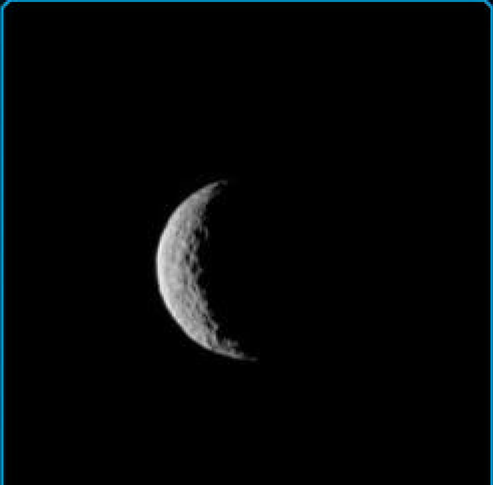
19 February 2015
This got astronomers talking: the basin located south of the equator isn't as deep as would be expected if it is an impact crater.



19 February 2015
Those bright spots are a little clearer now. One of them is dimmer than the other but they're both in the same basin.

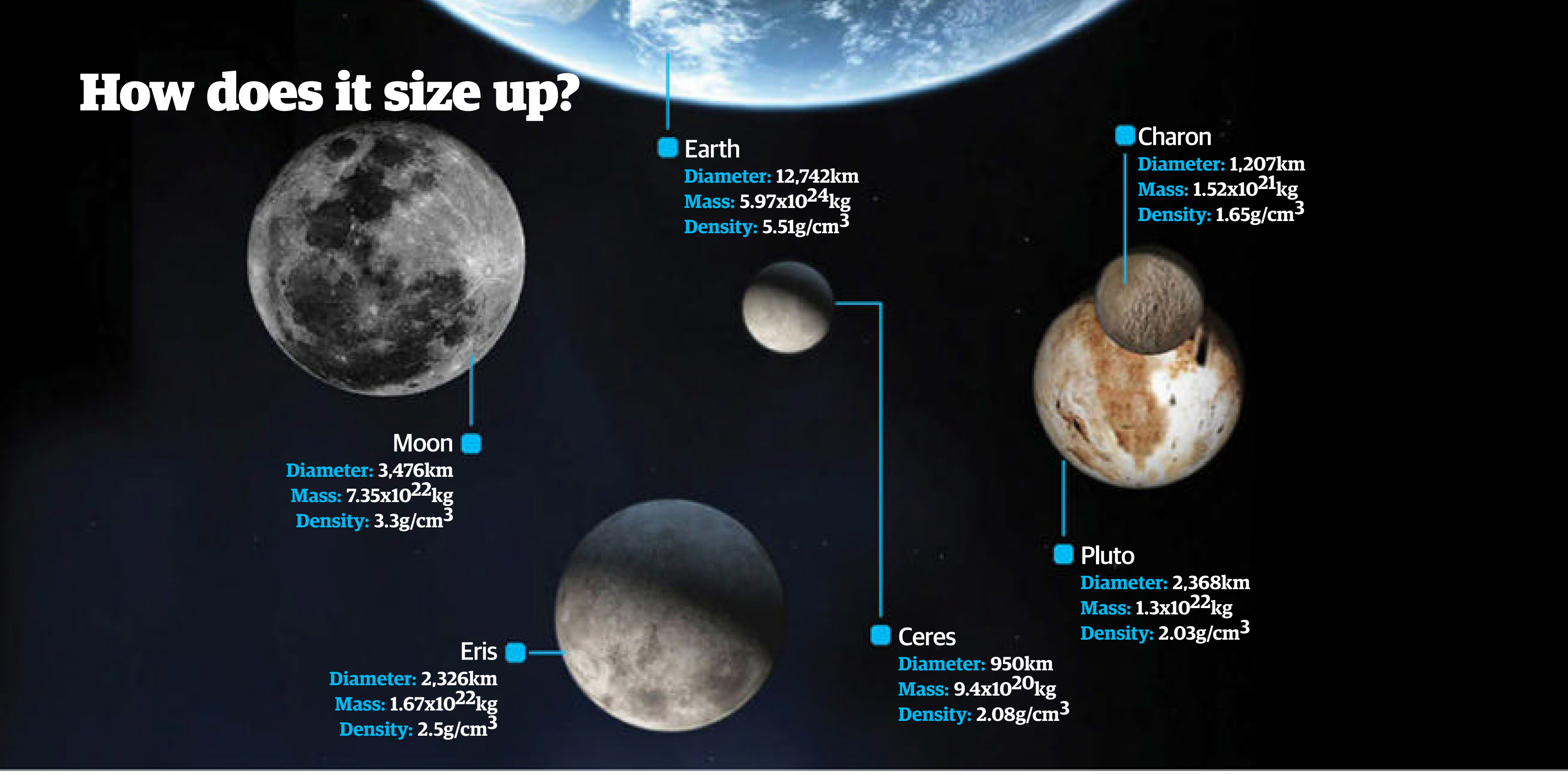


25 February 2015
Dawn took these photos at a resolution of 3.7km (2.3mi)-per-pixel). The spacecraft's position relative to Ceres and the Sun casts the dwarf planet in a half-shadow.



1 March 2015
Dawn is 48,000km (30,000mi) from Ceres at this point and this photo is at a scale of about 3km (1.9mi)-per-pixel.

How does it size up?



ions (atoms that are electrically charged) at a speed of some 40 kilometres (25 miles) per second. This creates a push that allows a spacecraft to move in the opposite direction.

"If the technologies on DS1 didn't work, we wouldn't put a more expensive mission at risk and if they did work they would be readily available," says Doctor Rayman. "So DS1 really paved the way for Dawn and other missions. It successfully demonstrated that ion propulsion could indeed work very well on an operational interplanetary mission."

Certainly, as the technology was refined, it made Professor Russell's proposed mission to the asteroid belt more viable. "In the year 2000 the stars started to align for us because Ceres and Vesta were in the same part of the sky," he says. "It means we could design a mission that went to Vesta and Ceres where we could not have done that in earlier years. This was something that only happens every 17 years so we were really very fortunate."

For missions to asteroids, comets and of course dwarf planets like Ceres, ion propulsion provides a low, steady acceleration that allows for closer inspection of celestial bodies. In the case of Dawn, it has allowed the spacecraft to leave one orbit, that of Vesta and propel toward that of Ceres. "To send a spacecraft from Earth to go into orbit around a distant extra-terrestrial destination, manoeuvre there and then break out of orbit to travel to another extra-terrestrial destination, before going into orbit around it is far beyond the capability of conventional chemical propulsion," explains Doctor Rayman.

"It simply requires too much manoeuvring. When a spacecraft leaves Earth, it uses a big rocket but we can't send a big rocket out to our first destination in order to allow the spacecraft to break free of its gravity and go to a second destination. Ion propulsion gives us this powerful capability."

The Dawn Mission will take advantage of the ion propulsion system to fly to different orbits around Ceres as it did around Vesta. The first observational orbit has been at an altitude of approximately 13,500 kilometres (8,400 miles). It enables astronomers to fully map the surface of the planet, observing it with the camera and two of the spacecraft's visible and infared spectrometers. Dawn will then descend to progressively lower orbits, obtaining images of increasing resolution, giving finer detail.

"In the second lowest orbit the spacecraft will actually map the surface six times," says Doctor Rayman. "So one of the times it will map it by looking straight down and making many revolutions. Then it will look off at an angle and fully map it again and then look off a different angle and then still another angle and another angle, building up what amounts to many stereo images."

This will give astronomers a good idea of how Ceres' surface looks while also allowing them to compile a detailed topographical map. "When we get down to our lowest altitude orbit, we will not only have all of the pictures as well as our visible and infrared spectra but we will measure the nuclear radiation being omitted from the surface," he adds. "Both gamma rays, which are a higher energy form of electromagnetic radiation beyond the visible, and ultraviolet and X-rays and neutrons which are a kind of sub-atomic particle. The energy will give us information on the elemental composition of the surface and the material just underneath the surface. By tracking the orbit of the spacecraft with exquisite accuracy we can measure the distribution of mass inside Ceres and that will allow us to understand what the interior structure is."

It hasn't been entirely plain sailing for the mission team, which has been communicating with Dawn a couple of times a week using the giant antennas of NASA's Deep Space Network in California, Madrid and Canberra. In September 2014, the Dawn spacecraft was hit by a burst of space radiation temporarily causing it to stop ion thrusting. At the time, Dawn had been following a carefully planned trajectory to Ceres and had been flying since 2012. But it was at a delicate thrusting stage and the mission team knew that any deviations from the intended thrust profile would affect the spacecraft's trajectory to Ceres.

"By simple bad luck, that is when the radiation burst occurred. We were no longer able to accomplish the original approach trajectory," says Doctor Rayman. "Or at least not without it taking an unnecessarily long time. Instead we designed a new trajectory, which is dramatically different and yet it got us into orbit at just about the same time."

Now that Dawn is orbiting Ceres, astronomers are getting a better picture of how the Solar System formed. That, for Doctor Rayman, is the most important aspect of the mission. "Anybody who has ever looked up at the night sky in wonder, anybody who has ever had any curiosity about the nature of the cosmos, anybody who wants to understand Earth and how we fit into the universe" he says. "One of the luxuries of a modern society is that we have the resources to invest in science that has real value." ■

> "We can measure the distribution of mass inside Ceres, that will allow us to understand what the interior structure is" **Doctor Marc Rayman**

As a massive Asteroid Belt object, Ceres could hold clues about the formation of the Solar System

INTERVIEW

Unlocking Ceres' scientific mysteries

The Dawn Mission team is led by Professor Christopher T. Russell. Here he discusses the science behind Dawn's journey to Ceres.

What kind of experiments will you be conducing at Ceres?

Dawn is a remote sensing mission. We will be determining the gravity of Ceres, looking at how it rotates and taking many mundane measurements. But we're also looking at the surface to see what is down there, whether there are mountains and valleys and evidence of water flow, whether craters have nice sharp rims and raised areas around them or whether they have relaxed. We're looking at whether or not the surface is really solid, rocky and icy or more fluid. The body might have a thin shell and an ocean underneath rather than a thick outer shell of ice or rock. So we're interested in the wetness of the body. Does it have a lot of water? If it does have water is it frozen or incorporated in the rock? We think around 40 per cent of Ceres is composed of water but we are trying to understand how water and rock interact in this particular body and exactly how much there is of each.

Why go to both Vesta and Ceres?

It's really important that we go to both. Vesta and Ceres are like two very different building blocks and they allow astronomers to begin visualising how the Solar System, or at least the terrestrial planets were created. Having two blocks is much better than only having one block, especially when one block is dry and one is wet. We can better decipher how the Solar System was formed.

What instruments are you using?

We're using a camera, which will let us see craters and mountains, perhaps old terrain here and new terrain there. To back that up we have a mapping spectrometer that measures in both the visible and the infrared. That will tell us what sorts of minerals are down on the surface because the different minerals will absorb sunlight or reflect it with different efficiencies. If we take a look at the spectrum of returned light from the surface, we can find these identifying features that tell us what minerals exist. That was very important at Vesta and we think it will be important at Ceres too. We also have a gamma-ray detector and a neutron detector, telling us the elements in the surface, how much aluminium, iron, oxygen and hydrogen there is and measuring the amounts. We can then start to determine the sequence of events and what type of events the body actually underwent.

So you'll get a glimpse of the past?

With Vesta we think we can look almost all the way back to the beginning of the Solar System, but the big mystery for Ceres is how far back we can see and if the surface is renewing itself. If it's a wet planet it's possible that on a much shorter timescale, the surface could get resurfaced. Materials could come out rapidly, flow easily and cover the surface so we are wondering what the surface really looks like compared to Vesta, where we had a good idea because once it was hit by something, that scar would stay there and remain for a long time.

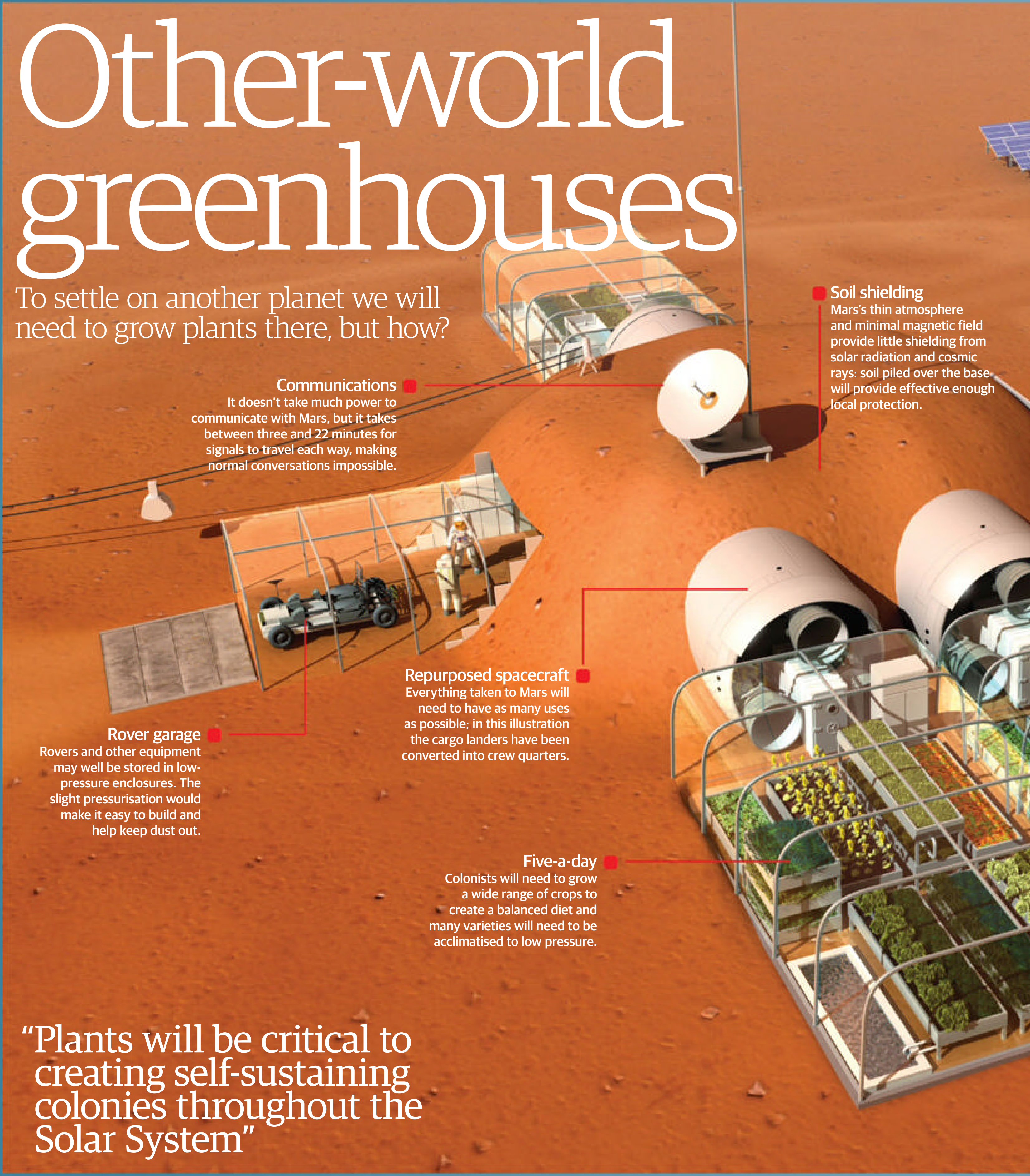
How long will you be studying the data for?

We will make some of the data publicly available as quickly as we can. It will take around three to six months but I expect the scientific community will pore over the data for many years to come. What happens is that people have new ideas and it takes a while to think through everything. We are still looking at the data from Vesta while arriving at Ceres.

© NASA; Maciej Rebisz

Other-world greenhouses

To settle on another planet we will need to grow plants there, but how?



Communications
It doesn't take much power to communicate with Mars, but it takes between three and 22 minutes for signals to travel each way, making normal conversations impossible.

Soil shielding
Mars's thin atmosphere and minimal magnetic field provide little shielding from solar radiation and cosmic rays: soil piled over the base will provide effective enough local protection.

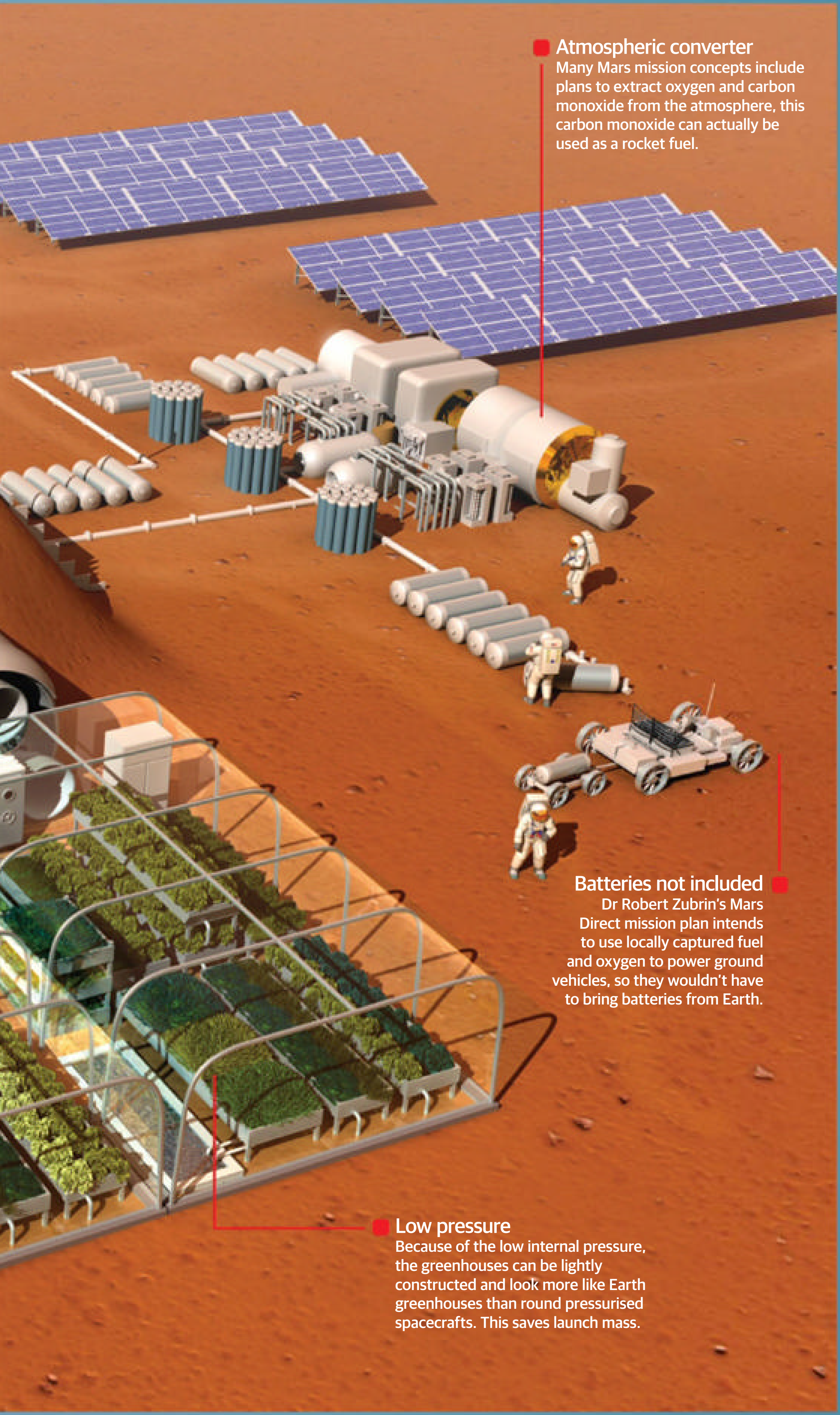
Repurposed spacecraft
Everything taken to Mars will need to have as many uses as possible; in this illustration the cargo landers have been converted into crew quarters.

Rover garage
Rovers and other equipment may well be stored in low-pressure enclosures. The slight pressurisation would make it easy to build and help keep dust out.

Five-a-day
Colonists will need to grow a wide range of crops to create a balanced diet and many varieties will need to be acclimatised to low pressure.

> "Plants will be critical to creating self-sustaining colonies throughout the Solar System"

Other-world greenhouses



Atmospheric converter
Many Mars mission concepts include plans to extract oxygen and carbon monoxide from the atmosphere, this carbon monoxide can actually be used as a rocket fuel.

Batteries not included
Dr Robert Zubrin's Mars Direct mission plan intends to use locally captured fuel and oxygen to power ground vehicles, so they wouldn't have to bring batteries from Earth.

Low pressure
Because of the low internal pressure, the greenhouses can be lightly constructed and look more like Earth greenhouses than round pressurised spacecrafts. This saves launch mass.

It is generally accepted that planetary colonies will have to grow their own food and no colony illustration is complete without an astronaut tending some crops. But like everything in space, this is not as easy as it looks.

Various plants have been grown on the International Space Station, but the problem for planetary greenhouses is not the lack of gravity, but the lack of pressure. In the initial stages of colonisation, most materials and equipment will have to be brought from Earth and if you can grow plants at a lower atmospheric pressure, it will save a lot of mass. First, the air supply itself may need to be transported from Earth and even if there are convenient deposits of ice to split oxygen from, you still need nitrogen and carbon dioxide to make plant-friendly air - these add mass. Second, greenhouses on the Moon and Mars would need to operate under little or no atmospheric pressure. Until colonies can make their own engineering materials, the structure will need to be transported. If the pressure inside can be minimised it will make it much lighter too.

Fortunately for would-be colonists, molecular biologist Rob Ferl, director of Space Agriculture at the University of Florida, is studying how plants respond to low-pressure, hypobaric, environments. "Plants have no evolutionary pre-adaption to hypobaria," says Ferl. "There's no reason for them to have learned to interpret the biochemical signals induced by low pressure. And, in fact, they don't. They misinterpret them."

Ferl has found that low pressures, at a tenth of the normal atmospheric pressure, make plants react as if there is a drought, even when they are provided with ample water and the air is kept humid. Water is drawn out of the leaves much quicker than normal and this stimulates the plants' genetic response to drought. The problem is that this will put stress on the plant and make growing it more difficult, they may close the tiny pores, called stomata, in their leaves to conserve water or allow their leaves to shrivel up and die. Ferl is studying these responses and testing biochemical alterations to change how plants react to this effect. To track how different genes respond to these conditions, Ferl's team have engineered plants with a protein that will fluoresce green when activated by them.

But there are benefits and potential earthly spin-offs to a low-pressure environment. Because water is flushed through the plant, toxins and hormones that govern plant growth are removed quicker too. This might keep plants healthy for longer and on Earth it may be possible to make use of this: fruit stored at a low pressure can be kept longer because it removes the chemicals that control ripening.

Ferl hopes to test plants for longer periods of time, over a wider range of pressures. Plants will be critical to creating self-sustaining colonies throughout the Solar System, "The exciting part of this, is that we're beginning to understand what it will take to really use plants in our life-support systems."

Attempts to live in space are often plagued by unexpected complications when living systems are removed from the conditions they evolved in. Thanks to Dr Ferl's work we should have one less problem to deal with when it comes to growing our own food on Mars.

© Adrian Mann

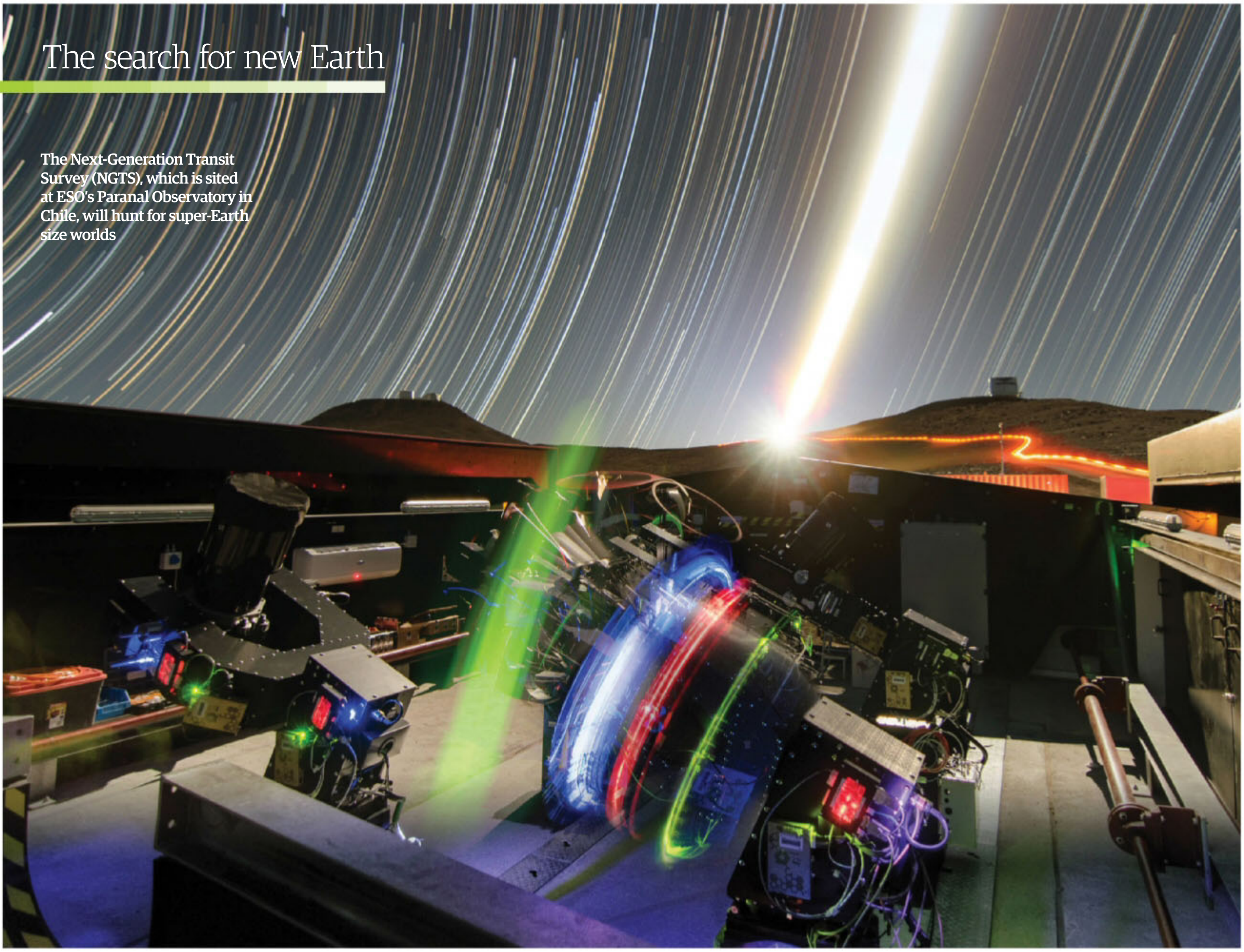
The search for
NEW EARTH

We've found over a thousand exoplanets in our galaxy, with millions more left to discover. So will we ever find Earth 2.0?

Written by Gemma Lavender

"How likely is life to begin? My answer is 'very likely', although intelligent life is possibly extremely rare"

Professor Brian Cox



The Next-Generation Transit Survey (NGTS), which is sited at ESO's Paranal Observatory in Chile, will hunt for super-Earth size worlds

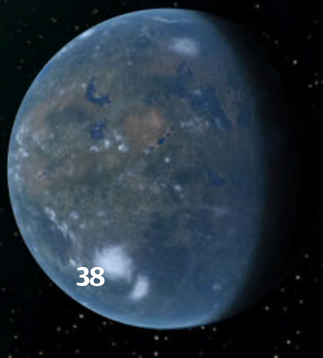
Astronomers think it's out there somewhere. The planet that's a dead-ringer, or at least close enough in comparison to our very own Earth. The discovery of such a world could provide tantalising evidence that we aren't alone in the universe and that life, whatever it may look like, can evolve elsewhere.

But we're yet to find this world and the truth is we have barely begun. The first exoplanets of any kind were not discovered until 1992 and there are still hundreds of billions of stars in our own galaxy that we have yet to study. And while we haven't yet found a planet that could serve as our Earth's doppelganger, we're getting close.

The Kepler Space Telescope holds the record for the most planets found. Even before the space telescope was built and launched back in 2009, astronomers knew what to task the mission with. Kepler was to search for potentially habitable worlds, hopefully like ours. Despite becoming crippled when two of its reaction wheels (which were used for accurately pointing the space telescope) failed, Kepler hasn't disappointed. "We've found [nearly] 2,000 confirmed planets around distant stars" states physicist Brian Cox, "And over a thousand of them have come through Kepler. Although you might say that's not many, even though it's more than none, which is what it was 20-odd years ago, the statistics are still quite surprising. Now we know that most stars have solar systems. We suspect that there are of the order of tens of billions of Earth-like planets in the Milky Way, not thousands, not millions, but billions of them."

In our search, astronomers have a checklist as to what really determines and therefore counts as 'potentially habitable'. When you compare Earth with the hellish conditions of Venus and the relatively freezing temperatures of Mars, our planet is like paradise and we are in a very good position to be able to work out what conditions might be like on other rocky worlds. For one, our planet rests in what is known as the habitable zone, a midway point that's not too hot and not too cold for liquid water to exist, thus being at an ideal distance from its star. "It's true that on our planet there's enough heat energy to foster bacteria deep down, so when we search

Top 5 Earth-like worlds



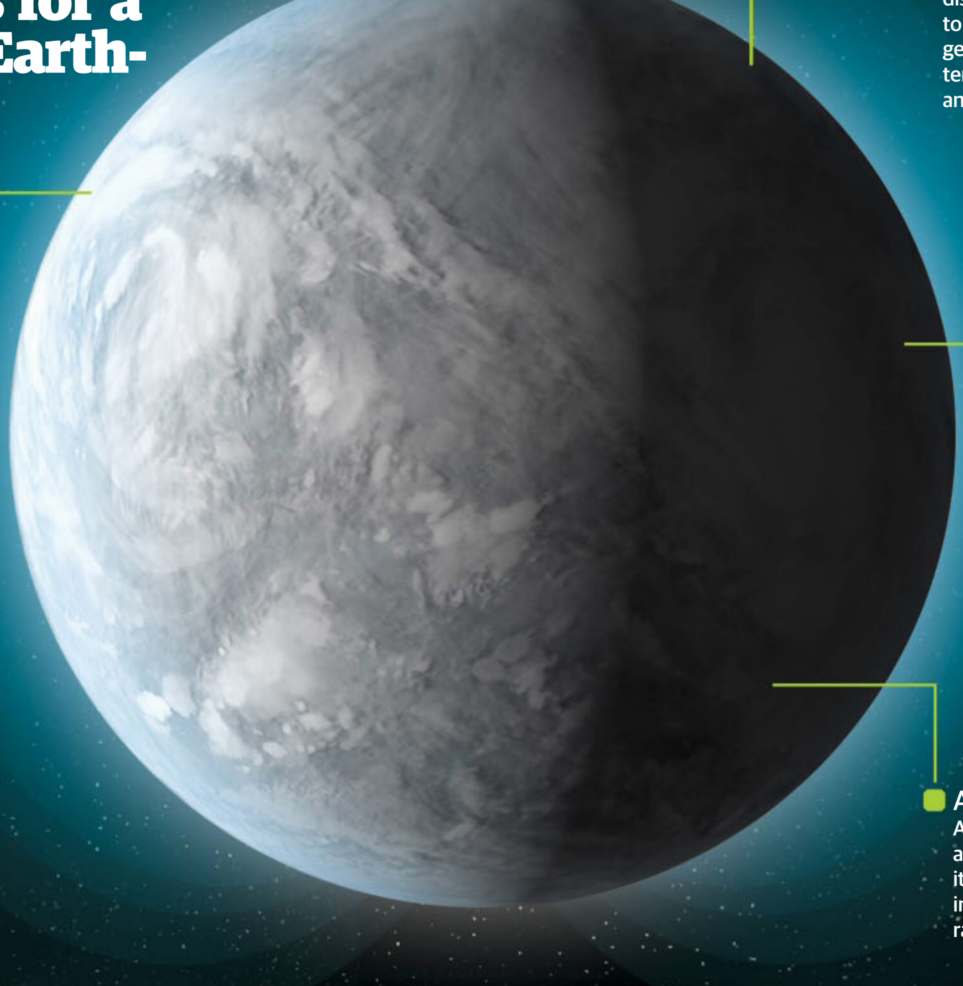
Kepler-438b

Announced as a confirmed exoplanet earlier this year, this world has a radius of 1.12 times that of Earth. It rests in the habitable zone of its red dwarf (a star that's cooler and smaller than our Sun) and astronomers believe that this planet is the most Earth-like to date.

Gliese 667Cc

Able to complete one lap around its parent star in just 28 days, Gilese 667C is a red dwarf that lies 22 light years away in the constellation Scorpius. Gliese 667Cc isn't the only planet that's a member of this system. One of two confirmed worlds, this rocky super-Earth is at least 3.9 times more massive than Earth.

Conditions for a habitable Earth-like planet



Just the right temperature
A planet must be at a suitable distance from its star in order to sustain liquefied water. In general, life is able to survive at temperatures between -15ºC (5ºF) and 115ºC (239ºF).

Less than 1.6-times the size of Earth
Astronomers have proven that planets up to 1.6-times the size of Earth generally follow the same processes that made our planet.

The right amount of nutrients
Nutrients are important to maintain life on a planet. Solid planets and moons are usually made up of the same general chemical makeup.

A magnetic shield
To deflect harmful space radiation as well as possible storms from their parent star, an Earth-like planet should have a magnetic field. This shield also ensures that the atmosphere doesn't whittle away to nothing.

A protective blanket
A world wrapped up in an atmospheric blanket keeps it warm, trapping heat in and keeping harmful radiation out.

for a new Earth, we'll be looking for one that orbits at a good distance from its star" states evolutionary biologist Richard Dawkins.

This is partly the reason we have not found a new Earth just yet. Our exoplanet-finding methods are biased toward finding planets in close orbits around their stars, rather than in orbits far enough away for the temperatures to be balmy, but not too hot for liquid water. That's not to say we can't use them to find small planets further from their stars, just that it is more difficult. For example, Kepler has to observe three transits of a planet before it can be considered a real candidate, but a planet like Earth will take several years to make this many orbits. So astronomers watching with Kepler have had to be patient. Finally, they are starting to reap the rewards, spotting alien planets that are looking more and more like Earth, but crucially we have not found one that seems the same yet.

This world should be rocky and have a mass that's not too dissimilar to Earth. It turns out that worlds with low mass are unable to hold on to an atmosphere since they would have a low gravity and a thick atmosphere like Earth's, which is vital in protecting any life forms from space radiation. According to Dawkins, gravity would also have an effect on the appearance of life should it evolve on a world that's substantially lighter or heavier than Earth. "Here we can say quite a lot because we understand quite a lot about the effect gravity has on life," he says. "A mouse-sized animal, which is on a planet with very strong gravity would have the proportions of a rhinoceros, as the proportions of each part of the body is affected by gravity."

Dawkins adds that under extremely strong gravity, even small creatures would need thick, strong limbs in order to support the weight of their bodies. "If gravity were weaker, an animal the size of a rhinoceros would have the spindly, long legs of a crane fly or a spider," he explains. Astronomers have found many worlds using Kepler and other planet-finding observatories, which are small enough to be rocky but which are more massive than Earth. These are called the super-Earths. Their stronger gravity means they could easily keep hold of their

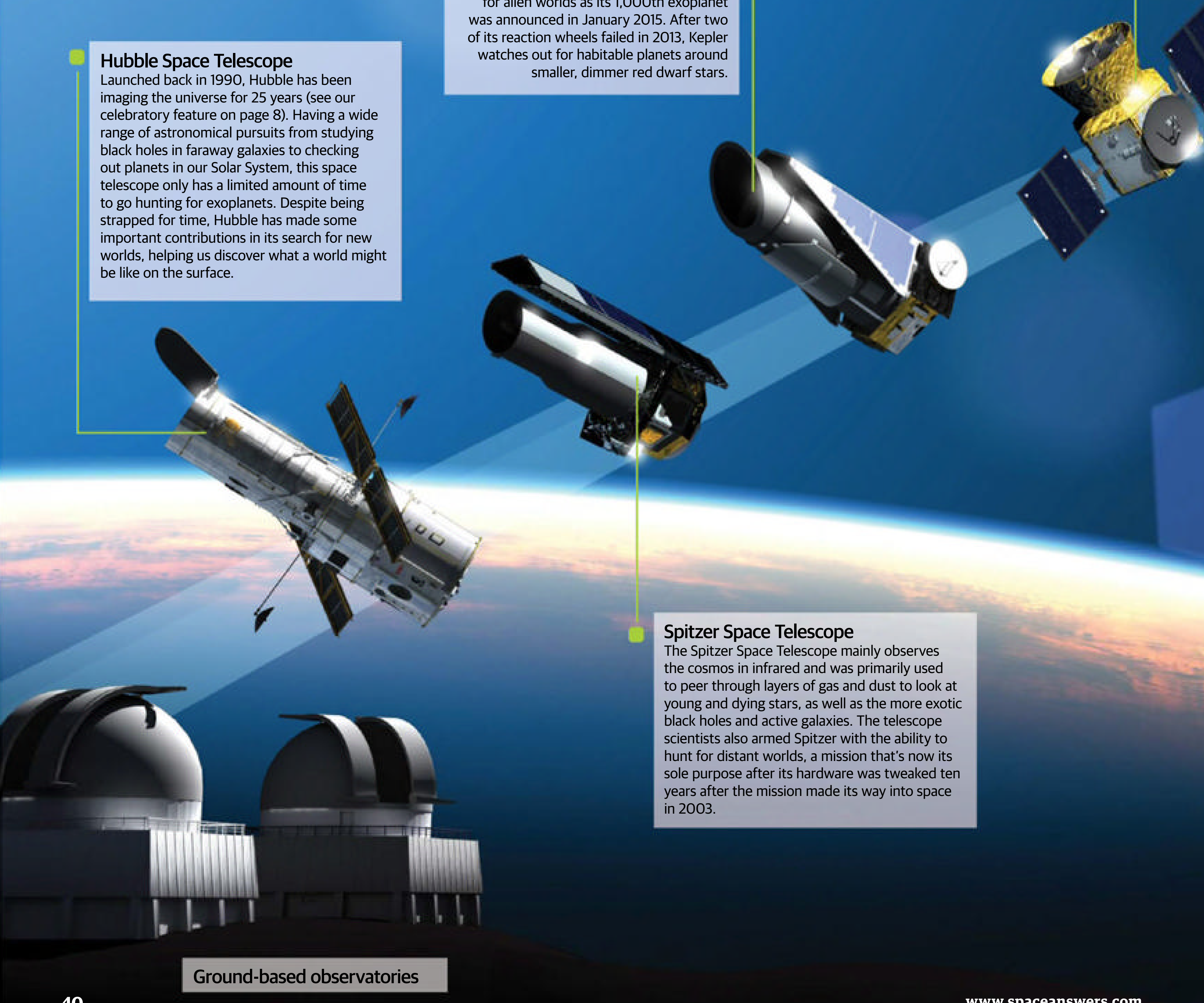
Kepler-442b
Discovered by NASA's Kepler spacecraft, Kepler-442b orbits an orange dwarf star 1,120 light years from Earth. It completes its orbit in roughly 112 days and has a radius 1.3 times that of Earth. It is thought to have a comfortable temperature similar to that of our planet.

Kepler-62e
Astronomers believe that this exoplanet is a water world, a warm place that's surface is dominated by liquid water. Kepler-62e lies some 1,200 light years away and takes 122 days to complete one lap around its red dwarf host star.

Gliese 832c
This hefty world orbits a red dwarf star and weighs in at around 5.4-times the mass of Earth. It's thought that on the whole, this planet has a temperature similar to Earth. Yet with an orbit that sees the exoplanet swing in and out of the habitable zone, Gliese 832c's climate can vary.

New world hunters

A fleet of space missions and ground-based telescopes have scoured the universe in the search for a new Earth and there's more on the way

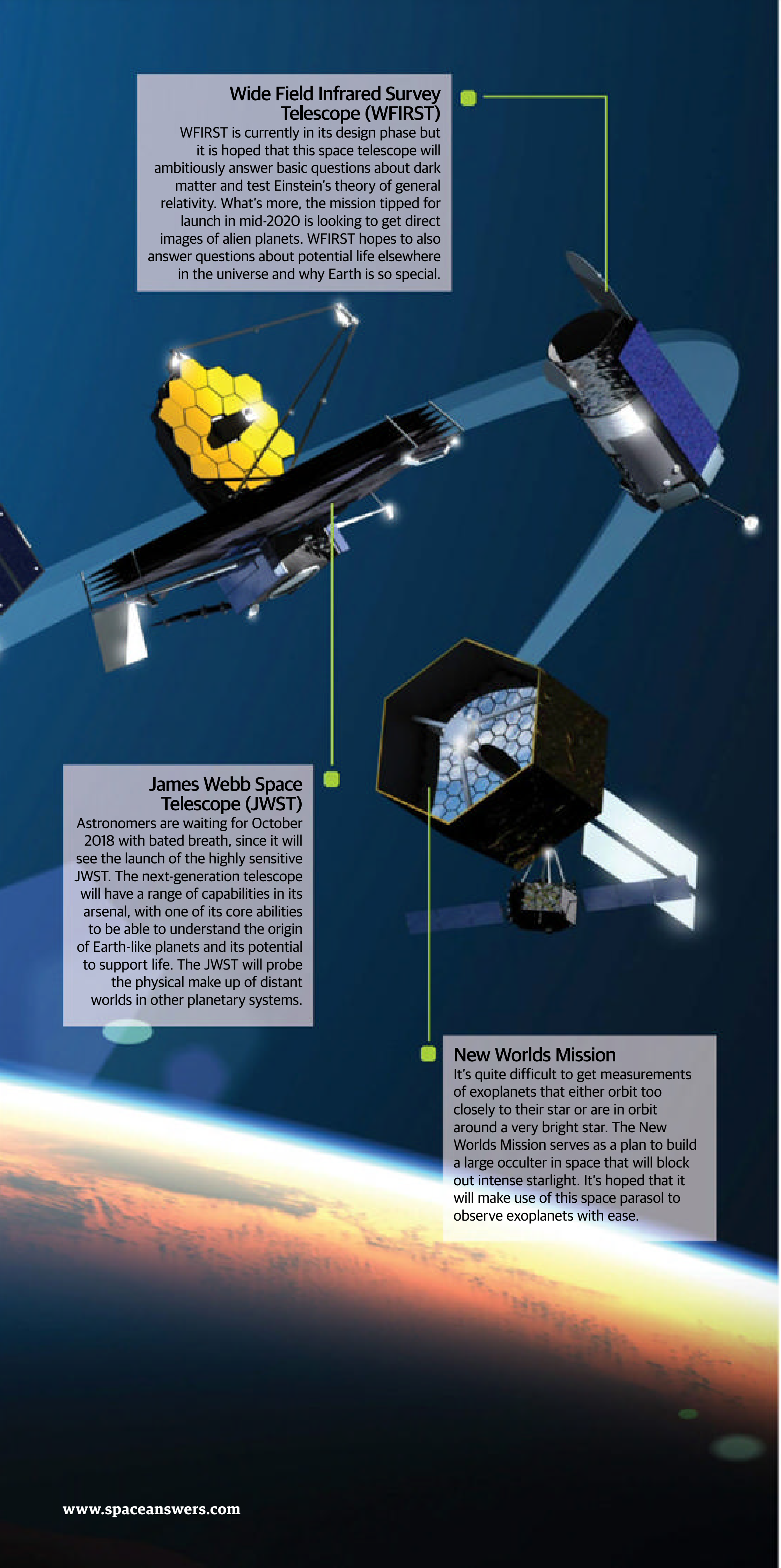


Hubble Space Telescope
Launched back in 1990, Hubble has been imaging the universe for 25 years (see our celebratory feature on page 8). Having a wide range of astronomical pursuits from studying black holes in faraway galaxies to checking out planets in our Solar System, this space telescope only has a limited amount of time to go hunting for exoplanets. Despite being strapped for time, Hubble has made some important contributions in its search for new worlds, helping us discover what a world might be like on the surface.

Spitzer Space Telescope
The Spitzer Space Telescope mainly observes the cosmos in infrared and was primarily used to peer through layers of gas and dust to look at young and dying stars, as well as the more exotic black holes and active galaxies. The telescope scientists also armed Spitzer with the ability to hunt for distant worlds, a mission that's now its sole purpose after its hardware was tweaked ten years after the mission made its way into space in 2003.

Kepler Space Telescope
Kepler is designed to look for Earth-like planets in orbit around other stars and more specifically, in the Milky Way galaxy. Staring at over 145,000 stars to monitor any dips in brightness that may signal the existence of a planet, Kepler has done well in its search for alien worlds as its 1,000th exoplanet was announced in January 2015. After two of its reaction wheels failed in 2013, Kepler watches out for habitable planets around smaller, dimmer red dwarf stars.

Transiting Exoplanet Survey Satellite (TESS)
Yet to make it outside the confines of Earth's atmosphere, the Transiting Exoplanet Survey Satellite, or TESS for short, will hopefully begin seeking out alien worlds in August 2017. Using an array of wide-field cameras, the 350kg (772lb) spacecraft will scan nearby stars that could have small planets orbiting them. TESS will be able to work out the size, mass, density and orbits of the planets it finds as well as examine small planets around stars just like our Sun.



Wide Field Infrared Survey Telescope (WFIRST)
WFIRST is currently in its design phase but it is hoped that this space telescope will ambitiously answer basic questions about dark matter and test Einstein's theory of general relativity. What's more, the mission tipped for launch in mid-2020 is looking to get direct images of alien planets. WFIRST hopes to also answer questions about potential life elsewhere in the universe and why Earth is so special.

James Webb Space Telescope (JWST)
Astronomers are waiting for October 2018 with bated breath, since it will see the launch of the highly sensitive JWST. The next-generation telescope will have a range of capabilities in its arsenal, with one of its core abilities to be able to understand the origin of Earth-like planets and its potential to support life. The JWST will probe the physical make up of distant worlds in other planetary systems.

New Worlds Mission
It's quite difficult to get measurements of exoplanets that either orbit too closely to their star or are in orbit around a very bright star. The New Worlds Mission serves as a plan to build a large occulter in space that will block out intense starlight. It's hoped that it will make use of this space parasol to observe exoplanets with ease.

atmosphere, but this would also mean that life would have to adapt.

Detecting planets is one thing, but detecting their atmospheres is another. Astronomers using the Hubble and Spitzer space telescopes have detected molecules of carbon dioxide, methane and water vapour in the atmospheres of some gas giants and a handful of super-Earths, but the smaller the planet, the thinner the atmosphere and the more difficult it is to take the measurements.

We don't know for certain what conditions are like on the exoplanets we've managed to detect, but thanks to Kepler, we've now got a bagful of planets that are thought to reside in the habitable zone of their star. The Earthliest of these is Kepler-438b, a world confirmed as a near-Earth-sized exoplanet with a radius of around 1.12 times our world's.

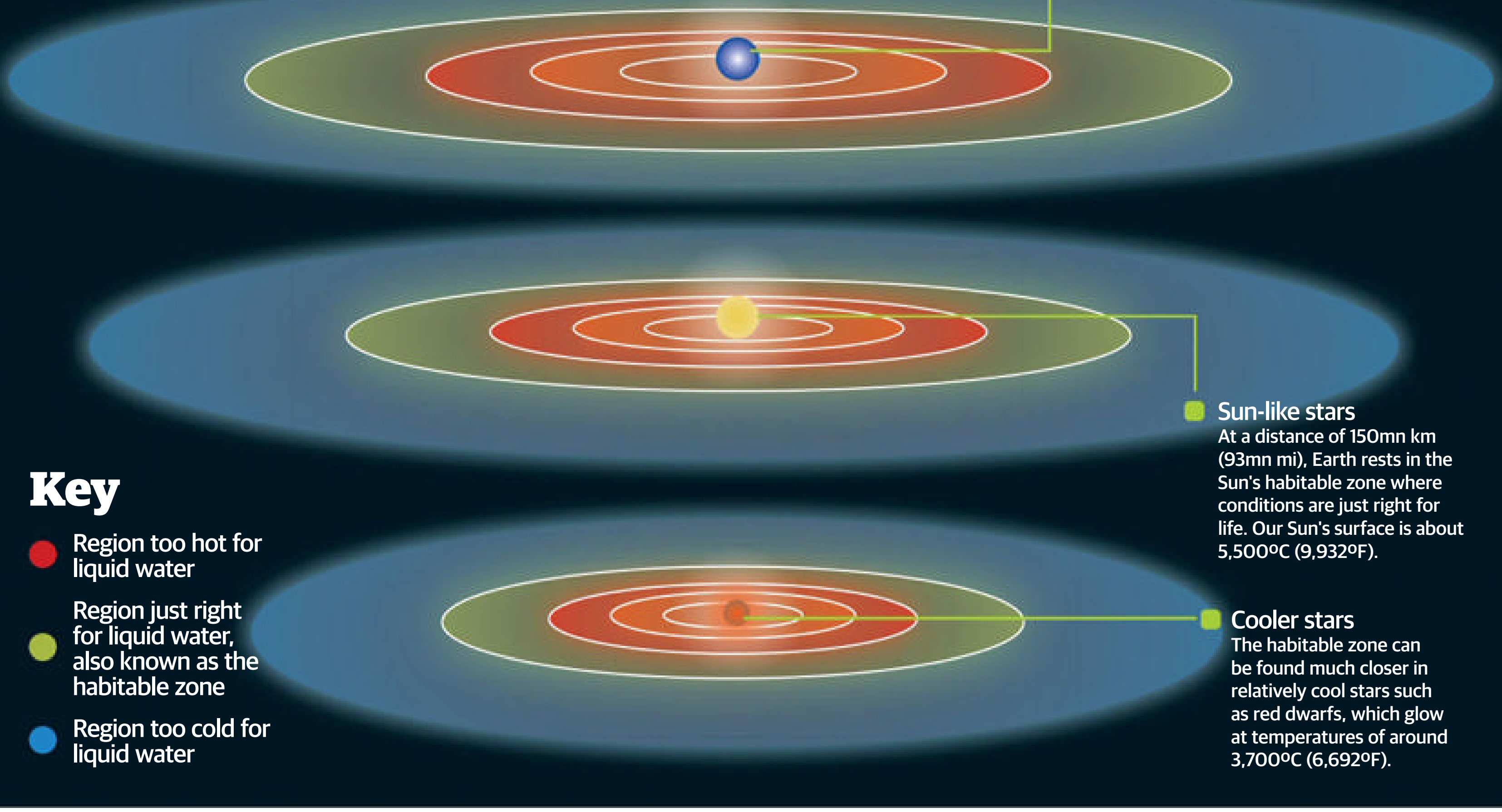
This is all well and good, except there is one crucial difference between Kepler-438b and our planet. Kepler-438b orbits what is known as a red dwarf, which is a cool and small star, much less impressive than our own Sun. Because red dwarfs are so cool, their surface temperatures are less than 4,000 degrees Celsius (7,232 degrees Fahrenheit), compared to the Sun's which is about 5,500 degrees Celsius (9,932 degrees Fahrenheit), the habitable zone is much closer to them than it is around a star like our Sun. Kepler-438b orbits its star once every 35 days at a distance of just 24.8 million kilometres (15.4 million miles), compared to Earth's 149.6 million kilometres (93 million miles). However, this distance from the star leads to some interesting possibilities. The planet has likely become tidally locked where the gravity of its star has interacted with the planet to slow its own rotation down, so that the length of its day becomes equal to its year. This means that it will always show the same face to its star, like the Moon does to Earth. On one hemisphere it will be warm and always daytime, while on the other it will always be nighttime. If there is no atmosphere, the far side will be in a deep freeze, but if there is a thick, Earth-like atmosphere, the warmth of the star could be redistributed around the planet, keeping the night-side warm enough potentially for liquid water to exist. Such a world would therefore not be a true mirror image of our planet, but the conditions could still be similar, with oceans of water and the potential for life. Red dwarfs are the most common type of star in the galaxy, so maybe the potentially habitable worlds in the Milky Way are tidally locked. In that case planets exactly like Earth are actually more rare than we thought.

Finding a habitable planet, an 'Earth 2.0', does not necessarily mean there will definitely be life on that world, but Professor Brian Cox is confident that there could be. "How likely is life to begin? My answer is 'very likely', although intelligent life is possibly extremely rare," he says.

The most Earth-like world in the Solar System besides Earth is the Red Planet, Mars. Some scientists speculate that it may have once harboured primitive microbial life-forms, but Mars is small and lost most of its atmosphere a long time ago. If there were ever any life, it probably would have disappeared at the same time. However, Brian Cox doesn't think we should use the Red Planet as an example of a habitable world.

Goldilocks zone

The ideal location around a star where Earth-like worlds might be found



Hot stars
The habitable zone is the region where liquid water can exist and is further from the star around hot stars, such as those with temperatures exceeding 30,000ºC (54,000ºF).

Sun-like stars
At a distance of 150mn km (93mn mi), Earth rests in the Sun's habitable zone where conditions are just right for life. Our Sun's surface is about 5,500ºC (9,932ºF).

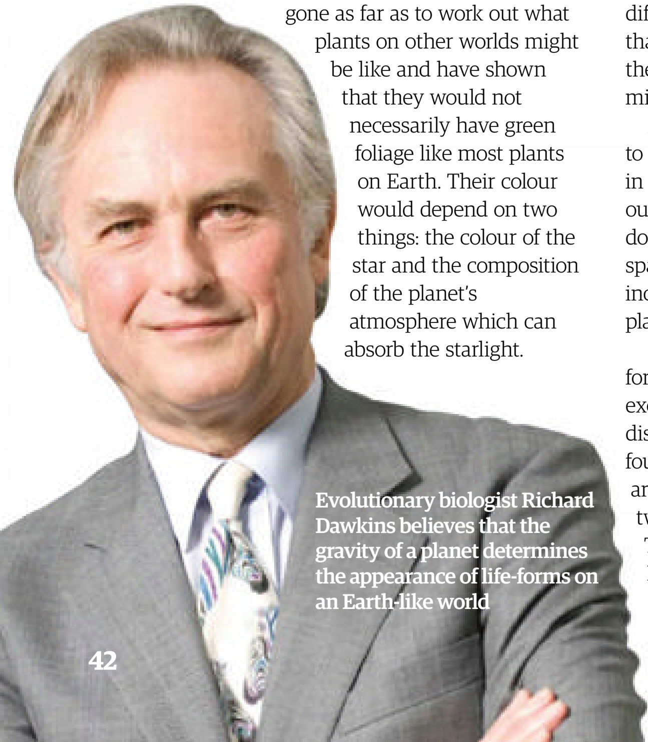
Cooler stars
The habitable zone can be found much closer in relatively cool stars such as red dwarfs, which glow at temperatures of around 3,700ºC (6,692ºF).

Key

- 🔴 Region too hot for liquid water
- 🟢 Region just right for liquid water, also known as the habitable zone
- 🔵 Region too cold for liquid water

"Mars is a bit of a red herring because I don't think it displays any of the characteristics that we should be looking for if we are looking to find life elsewhere in the rest of the universe," he says.

Maybe complex, intelligent life is a bit optimistic, but microbial life, or plant life could exist on another world like Earth. Scientists have even gone as far as to work out what plants on other worlds might be like and have shown that they would not necessarily have green foliage like most plants on Earth. Their colour would depend on two things: the colour of the star and the composition of the planet's atmosphere which can absorb the starlight.



Evolutionary biologist Richard Dawkins believes that the gravity of a planet determines the appearance of life-forms on an Earth-like world

Photosynthesis depends on the sunlight it is receiving and on Earth plants absorb the blue light scattered by the atmosphere as well as red light, reflecting away green light. A planet orbiting a hotter, brighter star where there is less red light and more yellow light, for example, might have plants that conduct photosynthesis by absorbing and reflecting different colours. Some scientists have speculated that plants on a world orbiting a red dwarf star, where there is a predominance of red and infrared light, might have black leaves.

Alien plants have actually been suggested as a way to detect habitable worlds. If the world were covered in vegetation, the colour of its leaves would stand out when astronomers study the planet's light. We do not yet have the technology to do this, but future space missions could have. Other biosignatures might include oxygen, carbon dioxide and water vapour in a planet's atmosphere.

Planet-finding missions and projects for the foreseeable future are focused mainly on finding exoplanets rather than characterising them and discovering if they are habitable. Kepler may have found over a thousand exoplanets, but new missions are set to dramatically increase that number. The two big upcoming missions are NASA's TESS, or Transiting Exoplanet Survey Satellite and ESA's PLATO, or PLAnetary Transits and Oscillations of stars. These will search for worlds that are transiting some of the brightest stars in the sky. Finding planets around brighter stars is preferred, because it is then easier to detect the atmospheres of these worlds and because the starlight that passes through, the atmospheres is brighter. Other planet-finding projects include NASA's James Webb Space Telescope (JWST), which will be able to look for planets as well as ESA's CHEOPS, or CHaracterising ExOPlanet Satellite and the Next-Generation Transit Survey at the European Southern Observatory in Chile. Perhaps one of these will find the first true Earth-like world but how will they know if they have? They can measure transits, which will tell us the size of the world and its orbit, but to determine if a planet is really habitable we need to know about its atmosphere. The JWST will be able to analyse the atmospheres of these worlds, as will another British-led mission called Twinkle, although this will be limited to studying the atmospheres of only the biggest worlds closest to their stars. Still, the technology used in Twinkle could be developed to one day be used on a much bigger space telescope capable of resolving a small, Earth-sized world. If its atmosphere contained lots of oxygen, carbon dioxide and water and if the planet's colour suggested there could be plant-life, then that would be a strong sign that we would have found another world like Earth. It would be our twin, but separated by dozens or hundreds of light years. ●

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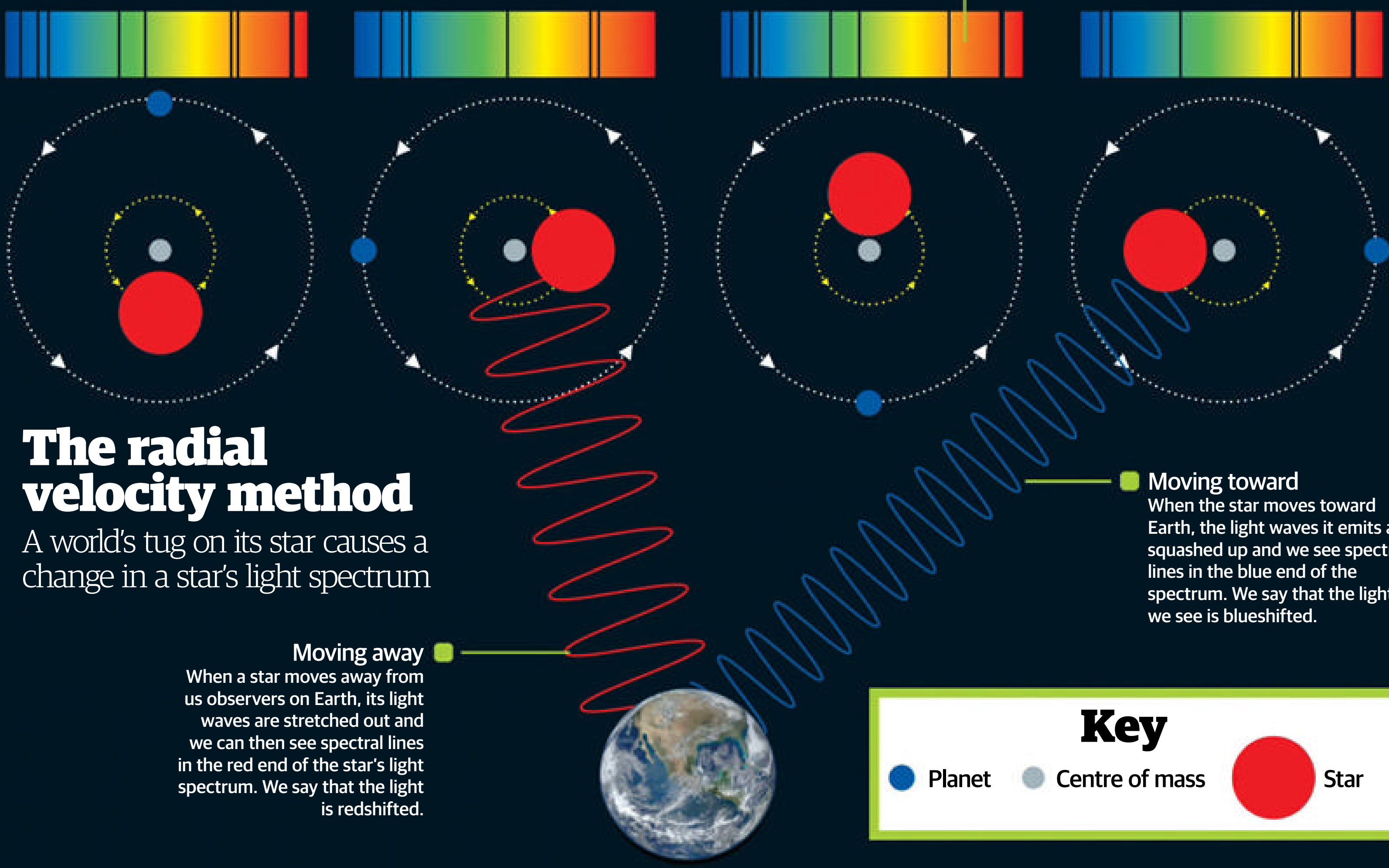
Planetary detection

How can we tell if we've found a planet? There are two ways: the radial velocity method and transit method



The star's light spectrum
The star's light spectrum changes as the star moves toward and away from Earth.

The radial velocity method

A world's tug on its star causes a change in a star's light spectrum

Moving away
When a star moves away from us observers on Earth, its light waves are stretched out and we can then see spectral lines in the red end of the star's light spectrum. We say that the light is redshifted.

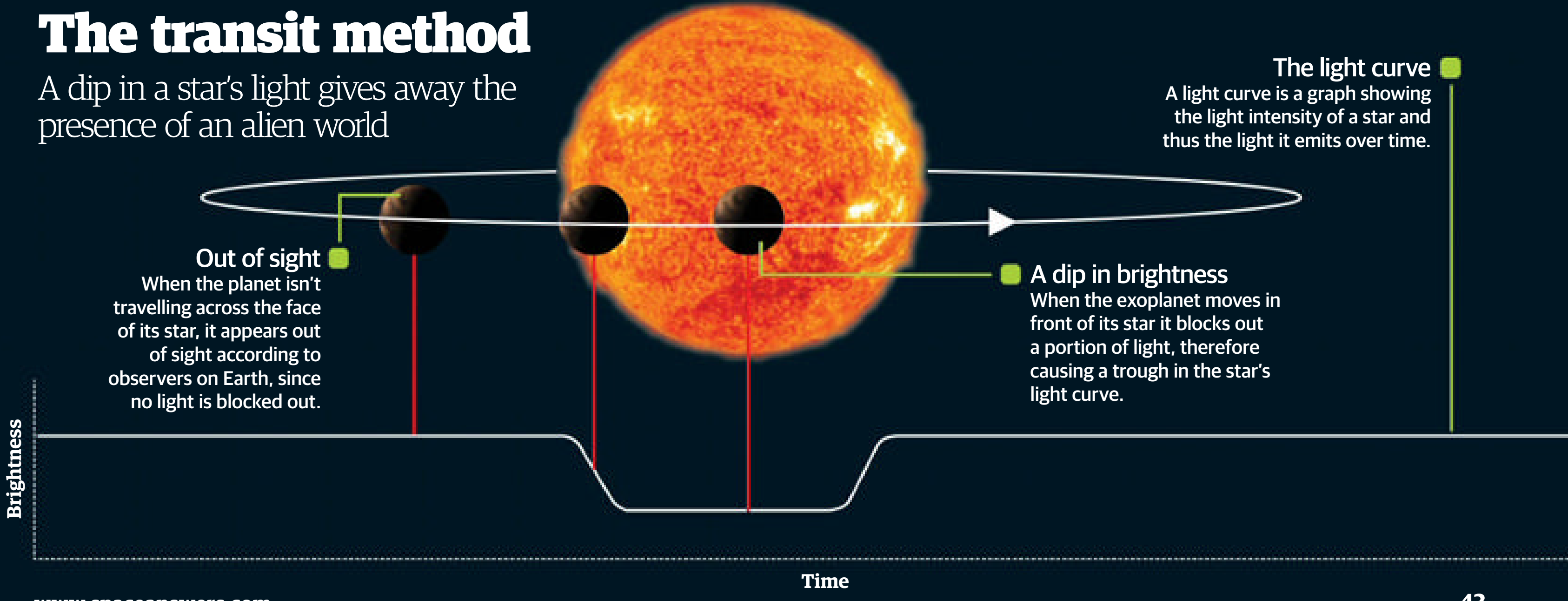
Moving toward
When the star moves toward Earth, the light waves it emits are squashed up and we see spectral lines in the blue end of the spectrum. We say that the light we see is blueshifted.

Key

● Planet ● Centre of mass ● Star

The transit method

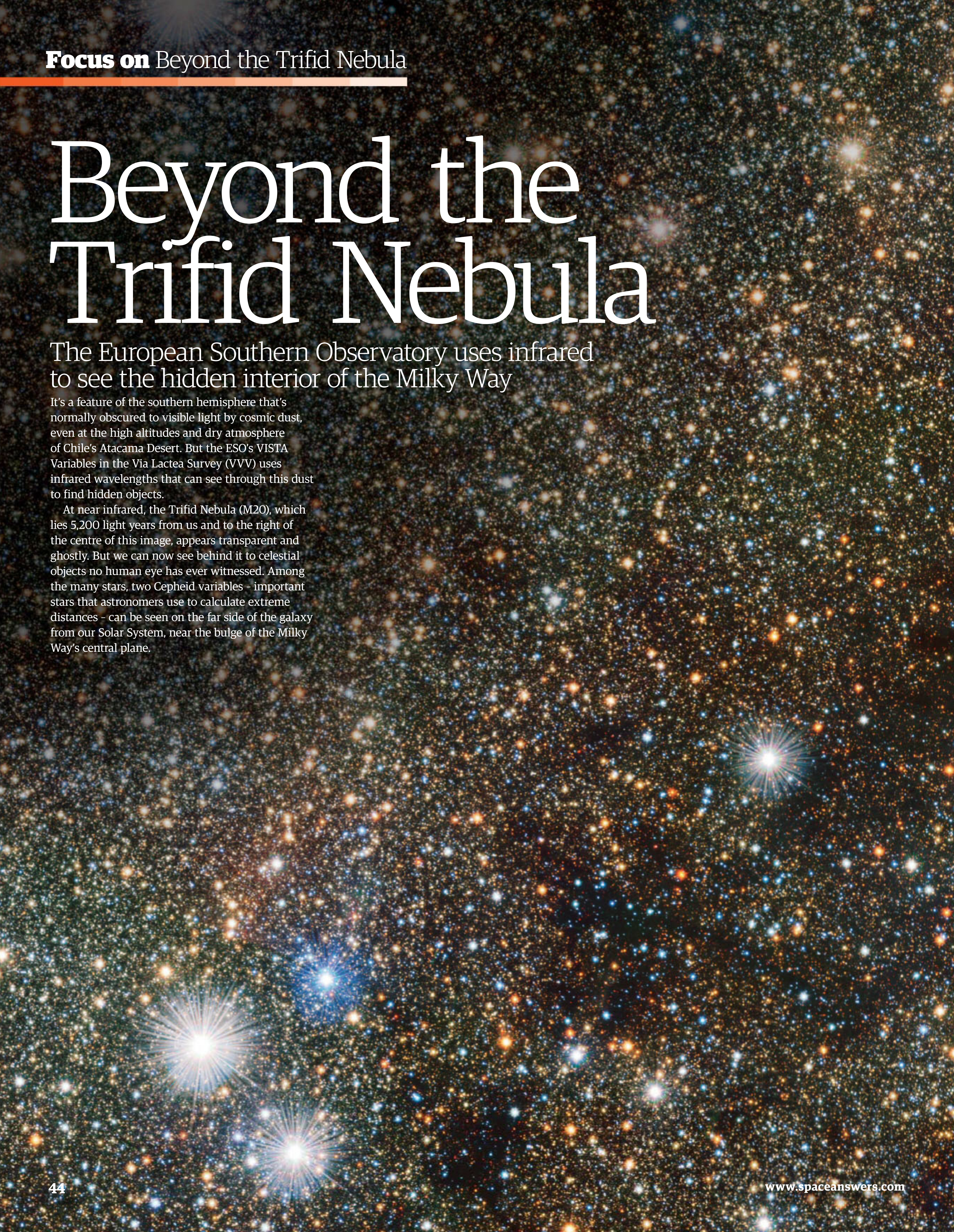
A dip in a star's light gives away the presence of an alien world



The light curve
A light curve is a graph showing the light intensity of a star and thus the light it emits over time.

Out of sight
When the planet isn't travelling across the face of its star, it appears out of sight according to observers on Earth, since no light is blocked out.

A dip in brightness
When the exoplanet moves in front of its star it blocks out a portion of light, therefore causing a trough in the star's light curve.



Beyond the Trifid Nebula

The European Southern Observatory uses infrared to see the hidden interior of the Milky Way

It's a feature of the southern hemisphere that's normally obscured to visible light by cosmic dust, even at the high altitudes and dry atmosphere of Chile's Atacama Desert. But the ESO's VISTA Variables in the Via Lactea Survey (VVV) uses infrared wavelengths that can see through this dust to find hidden objects.

At near infrared, the Trifid Nebula (M20), which lies 5,200 light years from us and to the right of the centre of this image, appears transparent and ghostly. But we can now see behind it to celestial objects no human eye has ever witnessed. Among the many stars, two Cepheid variables - important stars that astronomers use to calculate extreme distances - can be seen on the far side of the galaxy from our Solar System, near the bulge of the Milky Way's central plane.

The VISTA VVV survey is exploring the bulge of the central Milky Way, using infrared to see right through to the other side

© ESA

Explorer's Guide

Callisto

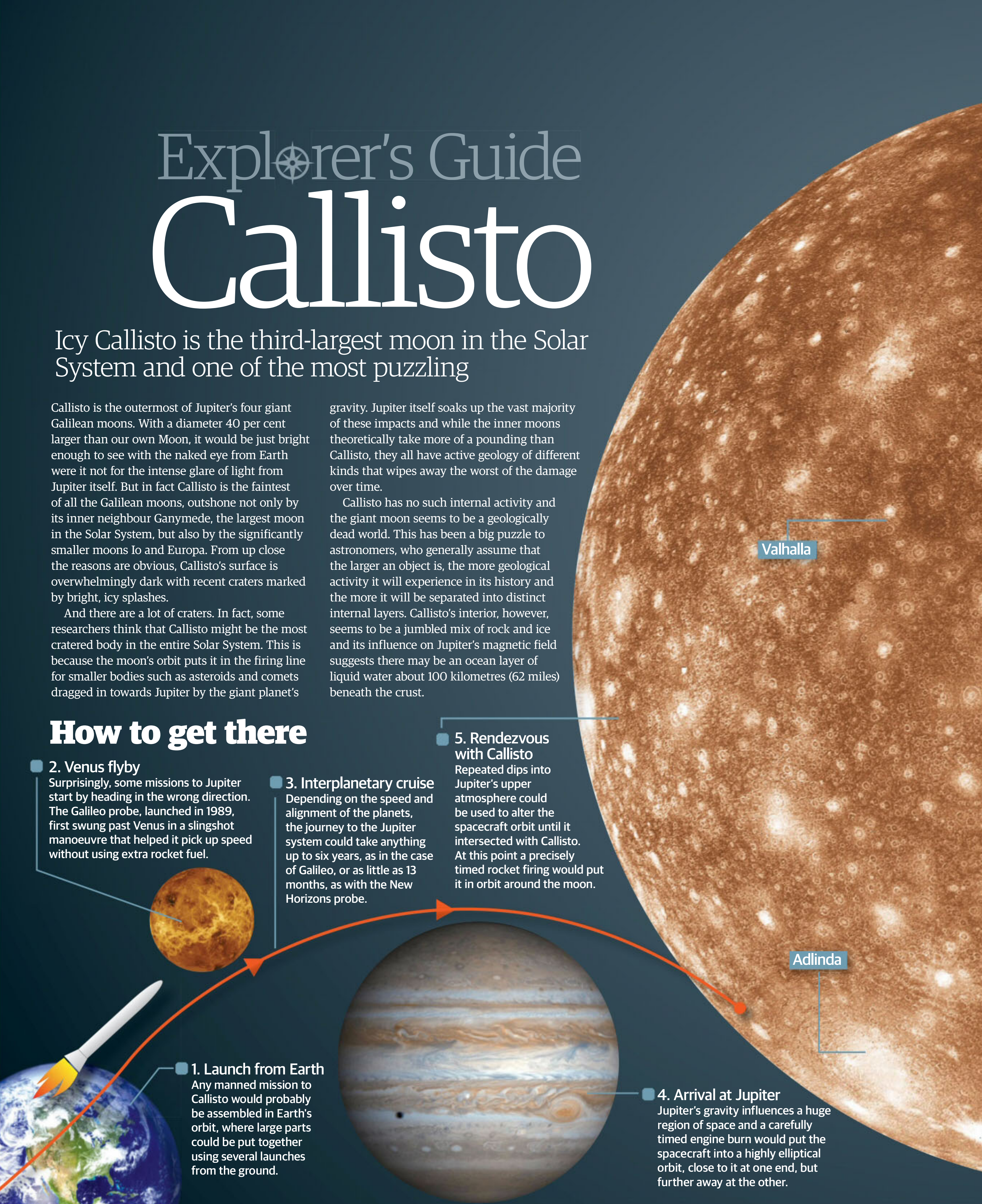
Icy Callisto is the third-largest moon in the Solar System and one of the most puzzling

Callisto is the outermost of Jupiter's four giant Galilean moons. With a diameter 40 per cent larger than our own Moon, it would be just bright enough to see with the naked eye from Earth were it not for the intense glare of light from Jupiter itself. But in fact Callisto is the faintest of all the Galilean moons, outshone not only by its inner neighbour Ganymede, the largest moon in the Solar System, but also by the significantly smaller moons Io and Europa. From up close the reasons are obvious, Callisto's surface is overwhelmingly dark with recent craters marked by bright, icy splashes.

And there are a lot of craters. In fact, some researchers think that Callisto might be the most cratered body in the entire Solar System. This is because the moon's orbit puts it in the firing line for smaller bodies such as asteroids and comets dragged in towards Jupiter by the giant planet's gravity. Jupiter itself soaks up the vast majority of these impacts and while the inner moons theoretically take more of a pounding than Callisto, they all have active geology of different kinds that wipes away the worst of the damage over time.

Callisto has no such internal activity and the giant moon seems to be a geologically dead world. This has been a big puzzle to astronomers, who generally assume that the larger an object is, the more geological activity it will experience in its history and the more it will be separated into distinct internal layers. Callisto's interior, however, seems to be a jumbled mix of rock and ice and its influence on Jupiter's magnetic field suggests there may be an ocean layer of liquid water about 100 kilometres (62 miles) beneath the crust.

How to get there



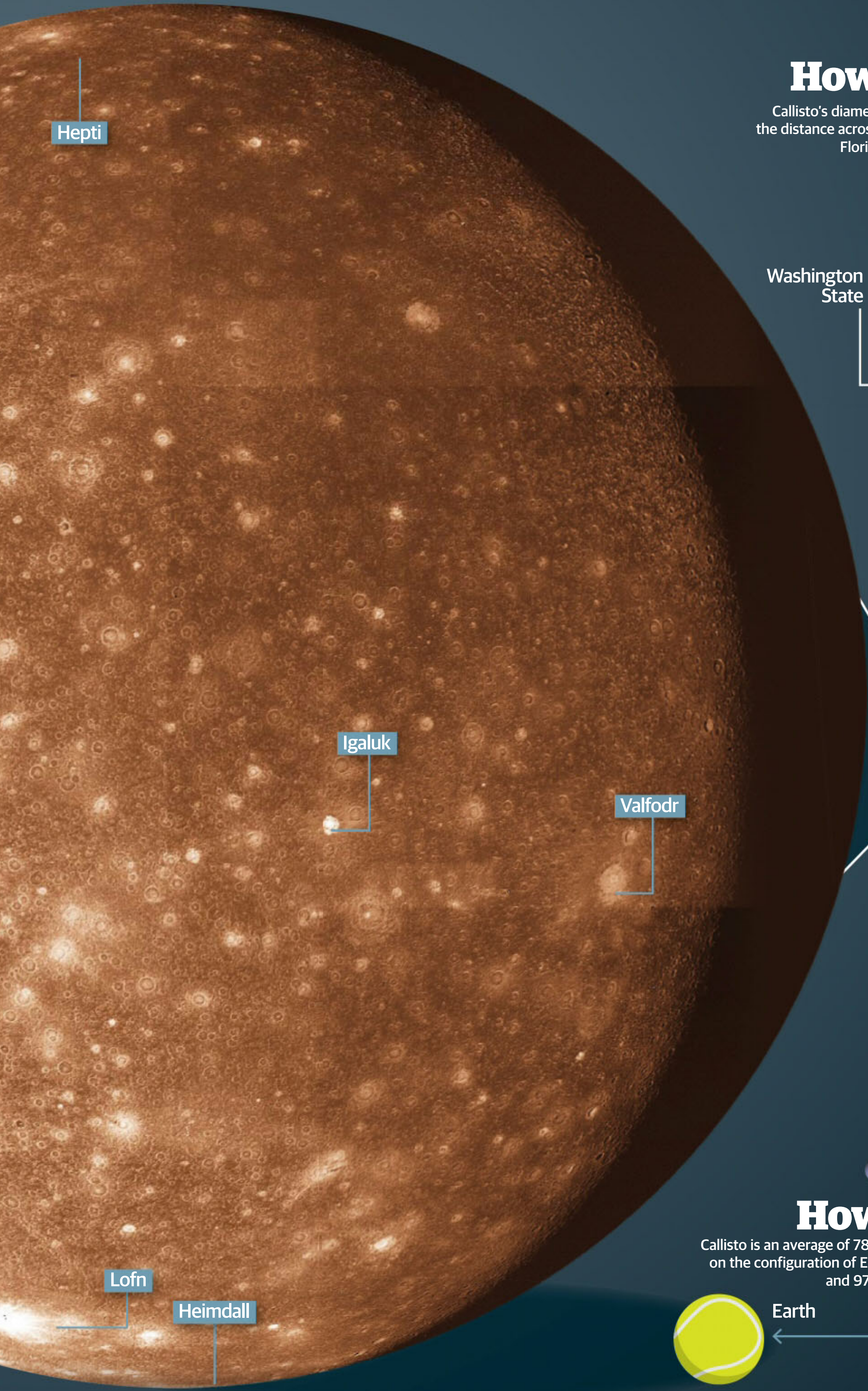
1. Launch from Earth
Any manned mission to Callisto would probably be assembled in Earth's orbit, where large parts could be put together using several launches from the ground.

2. Venus flyby
Surprisingly, some missions to Jupiter start by heading in the wrong direction. The Galileo probe, launched in 1989, first swung past Venus in a slingshot manoeuvre that helped it pick up speed without using extra rocket fuel.

3. Interplanetary cruise
Depending on the speed and alignment of the planets, the journey to the Jupiter system could take anything up to six years, as in the case of Galileo, or as little as 13 months, as with the New Horizons probe.

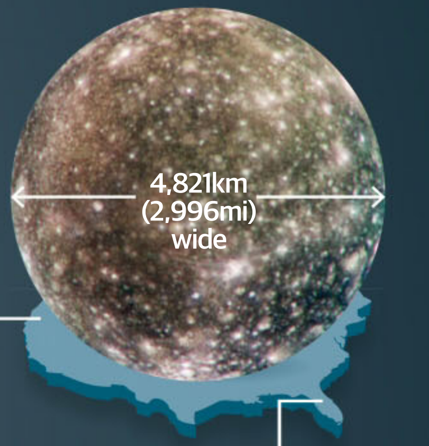
4. Arrival at Jupiter
Jupiter's gravity influences a huge region of space and a carefully timed engine burn would put the spacecraft into a highly elliptical orbit, close to it at one end, but further away at the other.

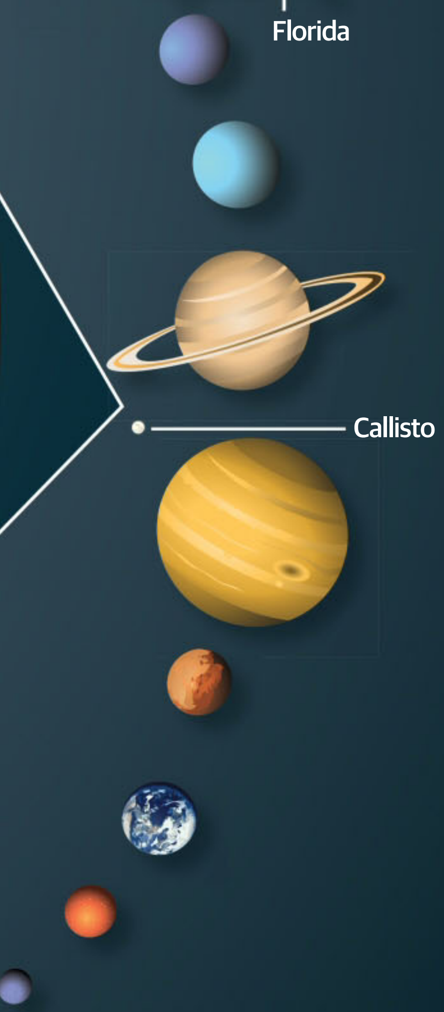
5. Rendezvous with Callisto
Repeated dips into Jupiter's upper atmosphere could be used to alter the spacecraft orbit until it intersected with Callisto. At this point a precisely timed rocket firing would put it in orbit around the moon.



How big is Callisto?

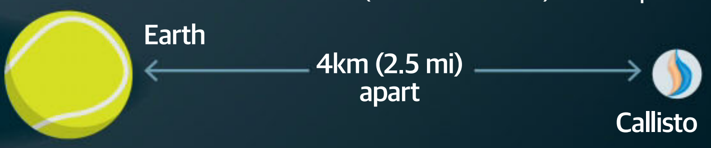
Callisto's diameter of 4,821km (2,996mi) is slightly larger than the distance across the contiguous United States, from the tip of Florida to the northwest edge of Washington State.





How far is Callisto?

Callisto is an average of 780mn km (485mn mi) from the Sun. Depending on the configuration of Earth and Jupiter's orbits, it varies between 588 and 970mn km (365 and 603mn mi) from our planet.



Top sights to see on Callisto

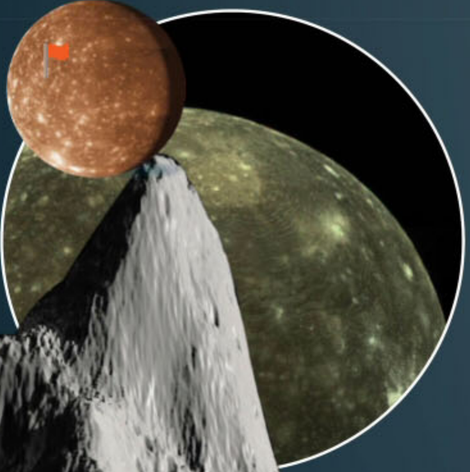
With no geological forces to reshape its surface, Callisto lacks features such as mountains, volcanoes and tectonic faults. Instead, the moon's most spectacular structures are undoubtedly two vast impact basins known as Valhalla and Asgard and like the majority of Callisto's features they take their names from Norse mythology. Each consists of a bright, flat region surrounded by rings of concentric hills. The bright central plains, known as palimpsests, are believed to be areas where a large impact from space broke through the moon's dark outer crust and allowed brighter, relatively slushy ice to well up from beneath. Valhalla's central palimpsest is about 360 kilometres (224 miles) across, but its overall diameter is about 1,900 kilometres (1,181 miles), making it one of the largest impact craters in the entire Solar System. Asgard is only a little smaller with a total diameter of 1,600 kilometres (994 miles). Careful studies of the ring structures have revealed a pattern of fractures radiating from the centre and crossing the concentric rings. Geologists think these might be linked to the presence of a hidden ocean layer about 100 kilometres (62 miles) below the surface.

Other types of impressive impact-related features are crater chains known as catenae, each of which is named after a river in Norse mythology. The chains, often stretching over hundreds of kilometres were created when the multiple fragments of a comet, disrupted by Jupiter's gravity but still following the same orbit, slammed into the moon rapidly. Astronomers saw something similar in 1994, when fragments of Comet Shoemaker-Levy 9 hit Jupiter.

On a smaller scale, however, much of Callisto's crust seems curiously eroded, small craters have often lost their neat structure, with well-defined crater walls replaced by clusters of knob-like pinnacles, often with patches of dark debris at their bases. After studying the arrangement of these pinnacles in relation to the weak heat and light from the distant Sun, scientists have concluded that they are probably created by gradual sublimation of ice on sunward-facing slopes. Callisto's crust is a mix of rock and various chemical ices (substances with relatively low melting points), including water and ice. Despite the intense cold, this ice can slowly transform directly into vapour at temperatures higher than around -100 degrees Celsius (-148 degrees Fahrenheit), sowly eroding Callisto's exposed outcrops into smooth isolated spires, with rock freed from the ice slowly rolling down their sides to accumulate at their bases.

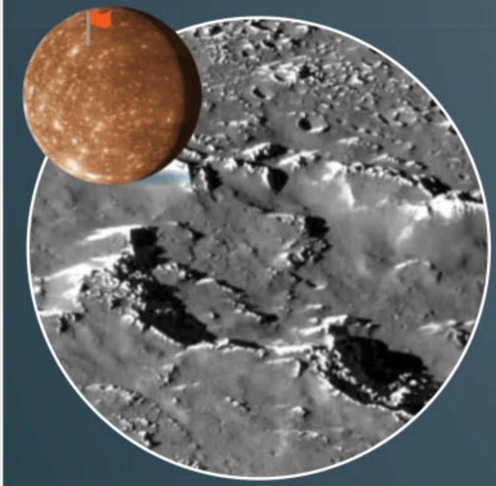
Valhalla

The Valhalla multi-ringed basin is the largest structure on Callisto, overlaid with several other major craters. It is thought to be at least 2 billion years old.



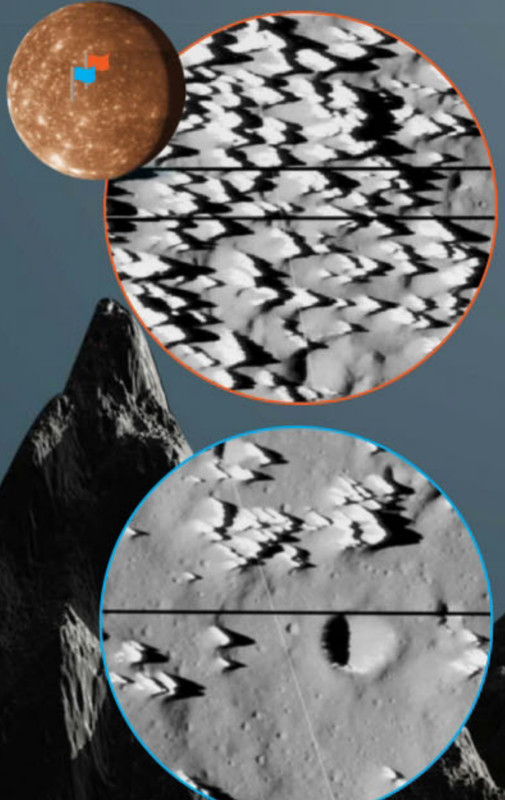
Gomul Catena

This series of depressions formed when fragments of a broken-up comet smashed into the surface of Callisto to form craters about 350km (217mi) long.



Pinnacle terrain

Some equatorial regions of Callisto are studded with jagged, knob-like peaks, created as heat from the Sun steadily erodes ice out of the landscape.



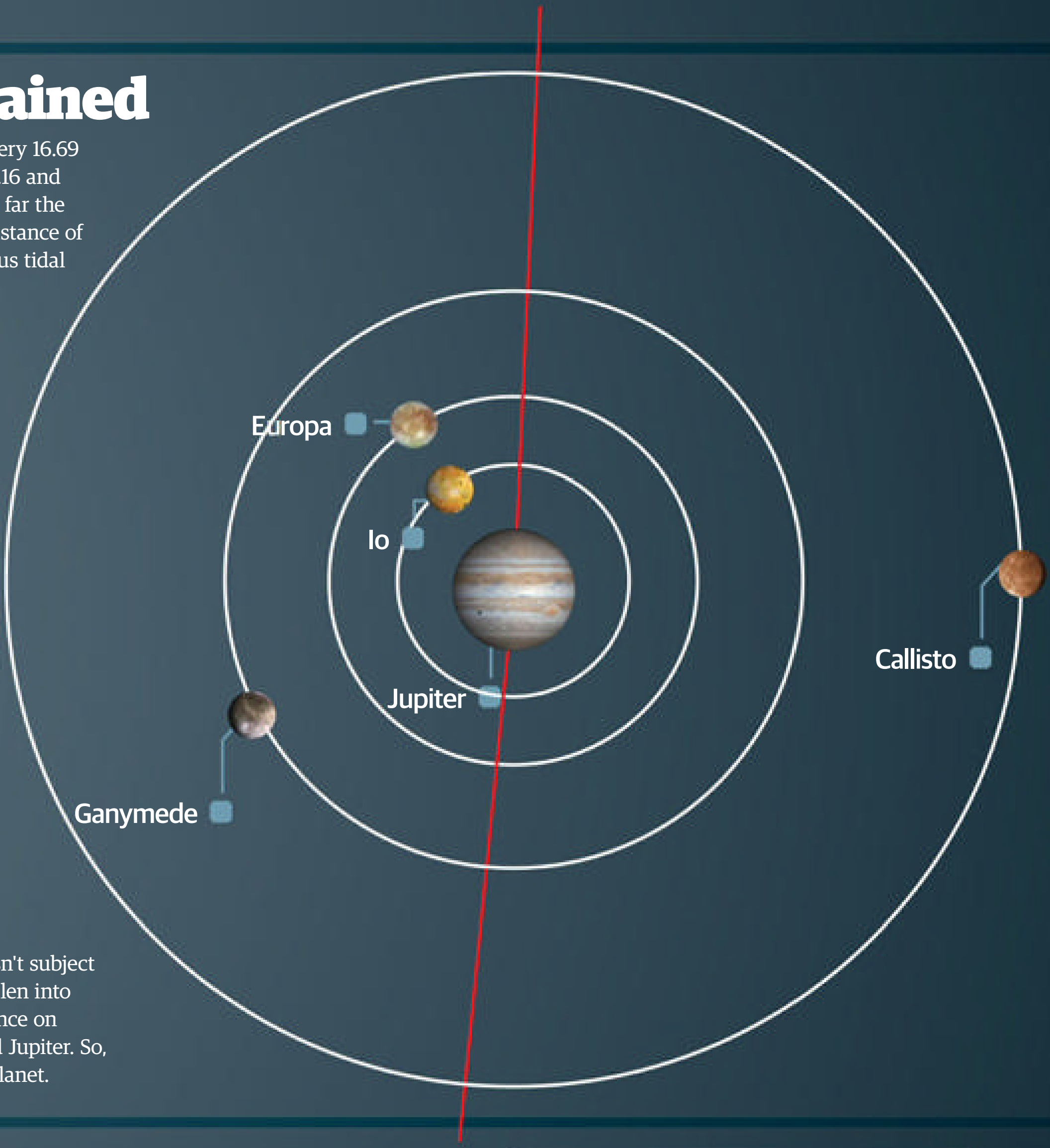
Crater haven

Over billions of years Callisto has seen more than its fair share of impacts. In fact, it's the most heavily cratered moon in the Solar System,

Callisto's orbit explained

Callisto follows a slightly elliptical orbit around Jupiter every 16.69 days, ranging between 1.87 and 1.90 million kilometres (1.16 and 1.18 million miles) from the giant planet. This makes it by far the most distant of the Galilean moons at almost twice the distance of Ganymede. Its distance protects the moon from the various tidal effects that influence its inner neighbours.

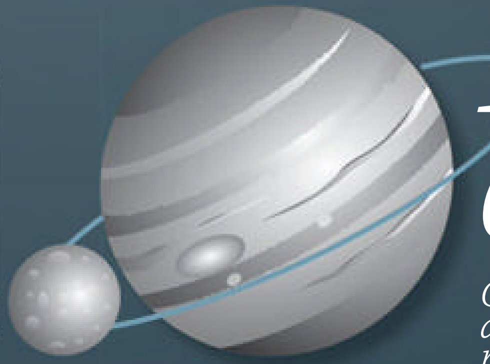
Callisto is seen here (bottom left) alongside Jupiter and Europa (in front of Jupiter)



Tidal locking

While Callisto's extreme distance from Jupiter means it isn't subject to the orbitial resonance (where planetary bodies have fallen into a regular, periodical orbit due to their gravitational influence on eachother), it's rotation is tidally locked to its orbit around Jupiter. So, like Earth's Moon, the same side always faces its parent planet.

Callisto in numbers



16.69 days

Callisto's orbital period around Jupiter and its rotation period

-139°C

The moon's average surface temperature

0.018

Callisto's mass compared to Earth

0.054

Callisto's volume compared to that of Earth

8.2 km/s

Callisto's speed along its orbit around Jupiter

0.126g

Callisto's gravity – roughly one eighth of gravity on Earth

1.834

Callisto's density in grams per cubic centimetre

Weather forecast

-195°C / -105°C

High **Low**

Callisto has no weather to speak of and the most tenuous of atmospheres, composed of oxygen and carbon dioxide that is gradually lost into space, but replenished as fresh gas sublimates out of its surface ices. The surface temperature ranges between about -195°C (-319°F) and -105°C (-157°F).

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Which are the biggest telescopes?

Monster mirrors and huge radio dishes around the world can provide us with revolutionary new views of the cosmos and there are even larger telescopes in development

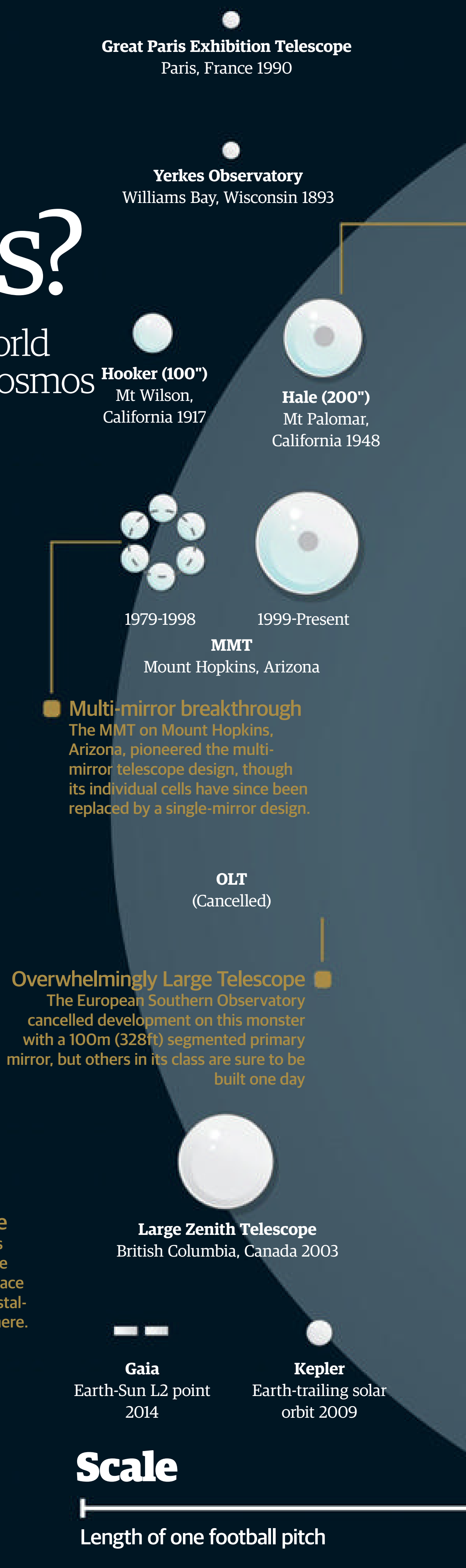
Astronomy is one field of human endeavour where bigger really is better. Ever since the first telescopes were invented in the 17th century, stargazers and instrument-builders alike have struggled to make bigger and better technology for observing the skies. The reasons behind this are twofold: first, larger telescopes have a bigger light grasp, collecting more light from faint celestial objects and directing it into our eyes, cameras and electronic detectors. Second, they have a greater resolving power, meaning they can magnify images better and separate closely spaced details.

Technical problems have often held back the development of larger telescopes, but breakthroughs in both materials and engineering since the 1990s have allowed the construction of some truly enormous instruments with capabilities earlier generations could barely have dreamed of. So which are the largest telescopes currently in operation? And what plans are there for even bigger observatories in the future?

The answer to this question is complicated by the way modern telescopes are designed. All of the biggest instruments are reflecting telescopes, with a large curving mirror surface to collect incoming light and direct it toward a focus, but since the 1990s, multiple-mirror telescopes have become common. These use an array of relatively small hexagonal mirrors to mimic the shape of a larger single mirror, with a framework of computer-controlled actuators compensating for problems such as distortion when the telescope is tilted at steep angles - a technique commonly known as active optics. Many of the largest instruments are in fact multiple-mirror telescopes such as the twin ten-metre (32.8-foot) Keck Telescopes on Mauna Kea, Hawaii and the 10.4-metre (34.1-foot) Gran Telescopio Canarias on La Palma island.

Advances in manufacturing have allowed more lightweight and slightly flexible single mirrors to be created. These are optical surfaces that can be kept in shape by the same active optics technology used on their multi-mirror cousins. Several single-mirror telescopes with diameters of up to 8.2 metres (26.9 feet) have been built in this way including the four major components of the European Southern Observatory's Very Large Telescope (VLT) in Chile, completed between 1998 and 2000 and Japan's Subaru Telescope, which is in Mauna Kea, Hawaii and was completed in 1999.

What's more, new techniques now allow light from neighbouring telescopes to be combined in a variety of ways, mimicking the power of an even larger instrument. For instance, light rays gathered by the four main VLT telescopes can be combined with those from several smaller outliers through a device called an interferometer to create a resolution equivalent to a 200-metre (656-foot) telescope. The Large Binocular Telescope in Arizona takes a different approach, with two 8.4-metre (27.6-foot) mirrors in a single mount, their combined light grasp is the same as a single mirror that is 11.8 metres (38.3 feet) across and their resolution matches that of a 22.8-metre (75-foot) telescope. But while these are the largest of today's telescopes, they won't hold their records for long, as construction is already underway on a new generation of monster observatories. Likely to be completed around 2020 is the Giant Magellan Telescope, which combines seven 8.4-metre (27.6-foot) mirrors on a single mount to mimic the light grasp of a single 22-metre (72-foot) mirror and the resolving power of one 24.5-metre (80.4-foot) wide. A couple of years later, however, it too will be supplanted by both the Thirty Meter Telescope being built on Hawaii, which will have a mirror composed of 492 hexagonal segments and the monstrous European Extremely Large Telescope (E-ELT), to be located in Chile. With a 798-segment mirror, the E-ELT will have an overall diameter of 39.3 metres (128.9 feet) and weigh more than 2,700 tons. But who can tell how long it will remain Earth's biggest telescope? ●



Multi-mirror breakthrough
The MMT on Mount Hopkins, Arizona, pioneered the multi-mirror telescope design, though its individual cells have since been replaced by a single-mirror design.

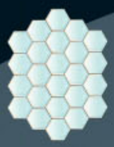
Overwhelmingly Large Telescope
The European Southern Observatory cancelled development on this monster with a 100m (328ft) segmented primary mirror, but others in its class are sure to be built one day

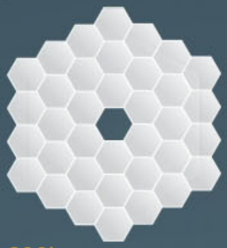
Scale
Length of one football pitch

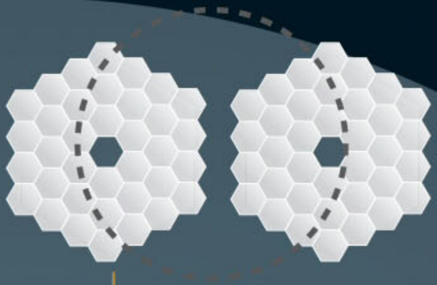
Hubble Space Telescope
Hubble's 2.4m (7.9ft) mirror is small in comparison with some earthbound giants, but the space telescope benefits from a crystal-clear view above the atmosphere.

Hubble's successor
The James Webb Space Telescope, planned for launch in 2018, will carry an 18-segment, 6.5m (21.3ft) primary mirror and is designed to view the sky mostly in infrared light.

Which are the biggest telescopes?


Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China 2009


Gran Telescopio Canarias
La Palma, Canary Islands, Spain 2007

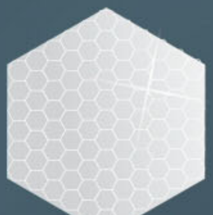

Keck Telescopes
Mauna Kea, Hawaii
1993-1996

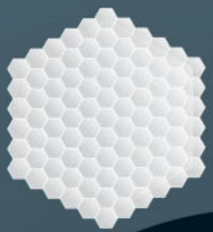
Long-term limit

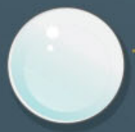
Completed in 1948, the 200in (5m) Hale Telescope at Mount Palomar was the pinnacle of observing technology and the largest successful telescope for much of the 20th century.

Twin breakthrough

The 10m (32.8ft) Keck Telescopes pioneered a large-scale multi-mirror design and could also be linked together by interferometry to mimic the performance of a much larger instrument.

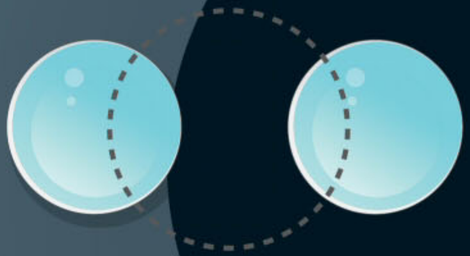

Hobby-Eberly Telescope
Davis Mountains, Texas 1996


Southern African Large Telescope
Sutherland, South Africa 2005


BTA-6 (Large Altazimuth Telescope)
Zelenchuksky District, Russia 1975

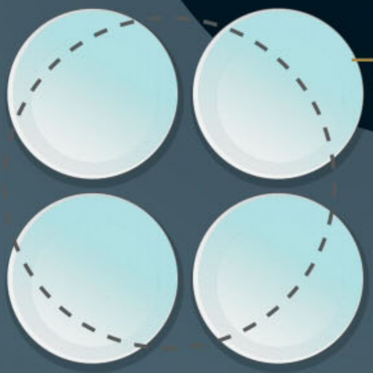
Expensive failure

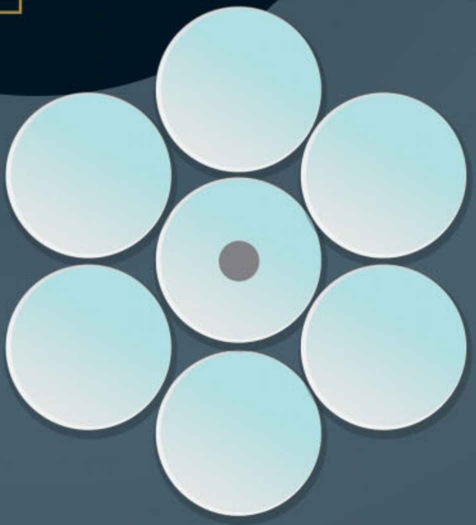
In the 1970s, this Russian attempt to build the 6m (19ft) telescope suffered from problems due to the weight of its enormous mirror.

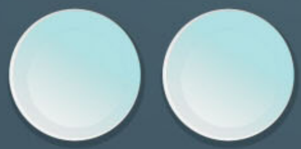

Large Binocular Telescope
Mount Graham, Arizona 2005

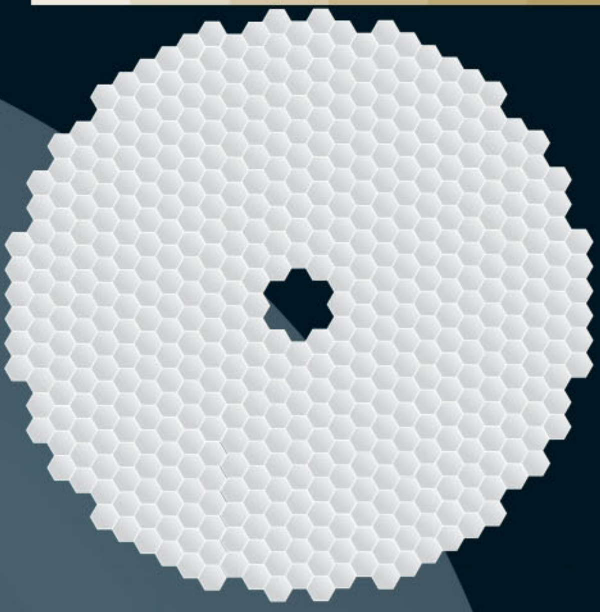
Working together

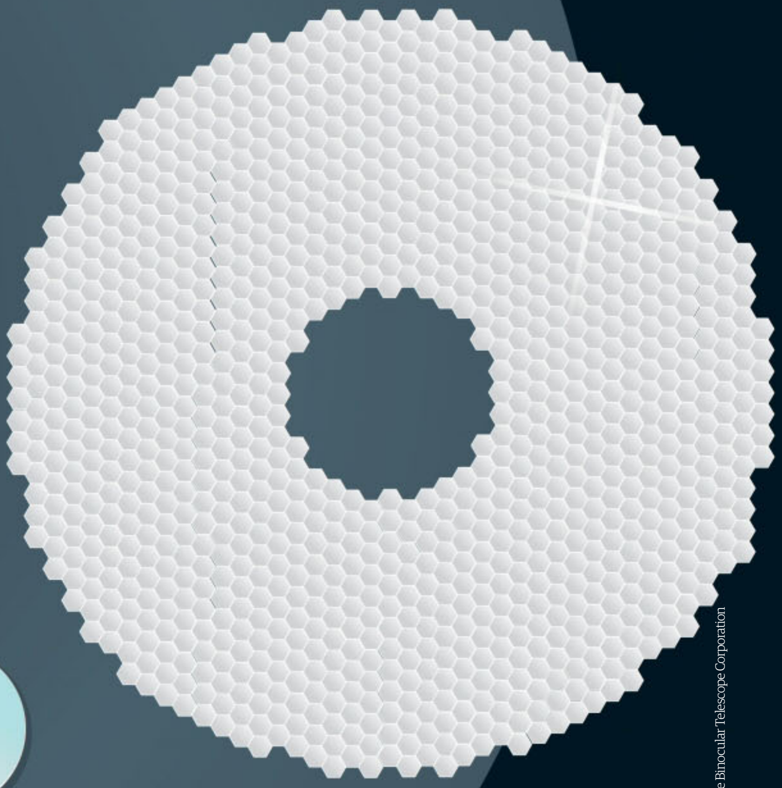
The four 8.4m (27.6ft) telescopes of the Very Large Telescope usually work separately but can be combined through interferometry for high-resolution work.


Very Large Telescope
Cerro Paranal, Chile 1998-2000


Giant Magellan Telescope
Las Campanas, Chile planned 2020


Magellan Telescopes
Las Campanas, Chile 2000-2002


Thirty Meter Telescope
Mauna Kea, Hawaii planned 2021


European Extremely Large Telescope
Cerro Armazones, Chile planned 2024

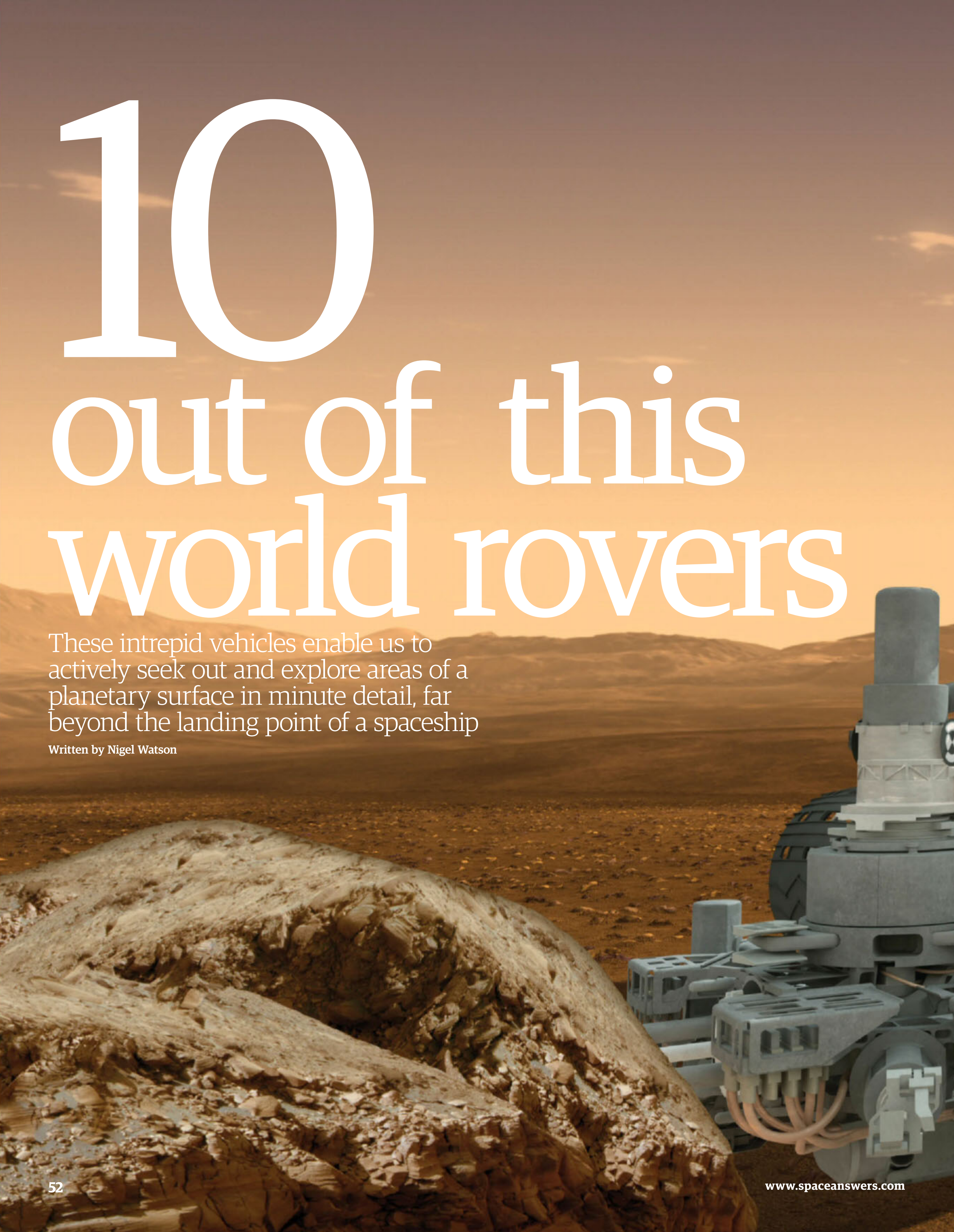
© Ed Crooks; Large Binocular Telescope Corporation

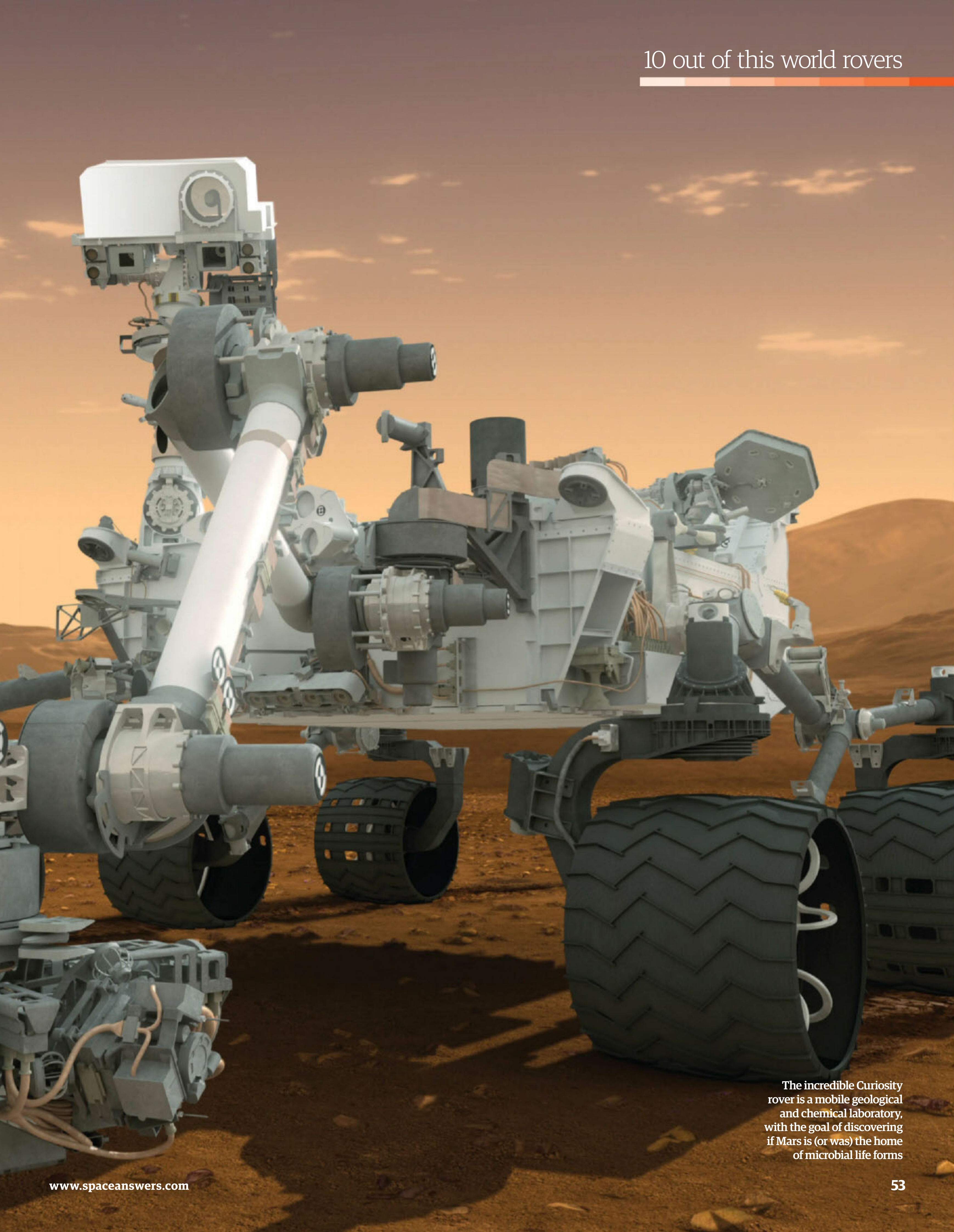
The Large Binocular Telescope on Mount Graham, Arizona

10 out of this world rovers

These intrepid vehicles enable us to actively seek out and explore areas of a planetary surface in minute detail, far beyond the landing point of a spaceship

Written by Nigel Watson





The incredible Curiosity rover is a mobile geological and chemical laboratory, with the goal of discovering if Mars is (or was) the home of microbial life forms

Roving vehicles have been sent to the Moon and Mars since the 1970s. They need to be robust enough to survive the massive g-forces at launch from Earth, the journey through space and the impact of landing. They are usually delivered to their destination by a lander craft that has retrorockets to slow down the descent, with parachutes and air bags also being used for landing on Mars. In the case of the large Curiosity rover, the sky-crane technique was used to make a more precise landing.

The use of rovers greatly adds to the amount of territory that can be explored. Orbital craft can take lots of pictures and collect data, which make us aware of the best places that are worth investigating in detail. A lander craft can bristle with tools and instruments to gather lots of information about a specific site, but you need a rover to seek out worthy areas to study in fine detail.

A rover requires a structure that protects its vital electronic systems and wheels, with steering and suspension that can cope with rough terrain and slopes. It also needs energy sources to power the motors and systems, usually from solar panels, batteries, nuclear heaters and cameras to provide information about its location and to guide navigation. Computers are required to process information and to navigate the vehicle, antennas send and receive data to robotic arms or hands that deploy equipment and use tools to obtain rock samples. Sophisticated rovers like Curiosity can operate independently until they receive further commands from one of the Earth-based mission control centres.

On 31 July 1971, Dave R. Scott was the first person to drive a rover on the lunar surface during the Apollo 15 mission. The first trip was a circuit around the Lunar Module and then a longer visit to the Elbow crater was carried out to obtain rock samples. Apollo 17 sent the third lunar vehicle, which made a record 35.74-kilometre (22.2-mile)-long journey. Since then, there have been no other manned vehicles, although several concept vehicles have been considered and they will no doubt follow the tracks of the robot rovers in the near future. ●

Lunar explorers

These lunar rovers have changed the way we see the Moon's surface

Key

🔵 USA

🟠 China

🟢 USSR

01

Lunokhod 1

Country: USSR
Launch date: 10 November 1970
Mass: 756kg (1,667lb)

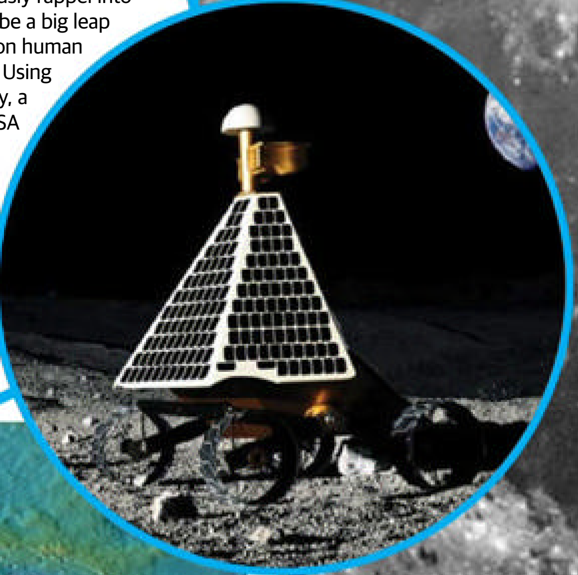
Looking like a tin bath with wheels designed by Wallace and Gromit, it isn't the most stylish lunar rover and its achievements were overshadowed by the US Apollo manned Moon landings, even though it is the first remote-controlled lunar rover. The craft had eight wheels that each had an electric motor for better manoeuvrability. When it landed on the Sea of Rains, a crew of two engineers drove it off the landing stage of the Luna 17 spacecraft. The driver used images from the rover's two pairs of TV cameras to plot its course, while the other crew member steered the craft's aerial to keep it in line with Earth, maintaining radio communication and control. To provide power to the batteries, Lunokhod 1 opened its convex lid during the day to expose solar cells positioned inside. During the night, the lid was closed and a radioisotope heater kept its components warm. It performed incredibly well, taking an impressive 500 soil samples, sending back 20,000 close-up and 206 panoramic pictures of the lunar surface and travelling a total of 9.93 kilometres (6.17 miles).

02

Astrobotic Lunar Spelunker

Country: USA **Launch date:** Concept vehicle
Mass: To be confirmed

This is a rover concept that would be employed to explore skylights and tunnels on the Moon or Mars. These geological structures are too dangerous for astronauts to explore, so the alternative is to use robots that could autonomously rappel into and traverse these underground voids. This would be a big leap from current roving vehicles, which depend heavily on human controllers, meaning they tend to move very slowly. Using the technological expertise of Astrobotic Technology, a 'Spelunker' concept mission has been funded by NASA that would land a spacecraft near a lunar cave or skylight. A power and communications hub would be lowered into the void, releasing roving robots to carry out a full survey of the environment. This activity would add to our knowledge of the geology of these localities, making way for human explorers and even human habitats, testing the capabilities of these robotic devices operating in these hidden lunar realms.

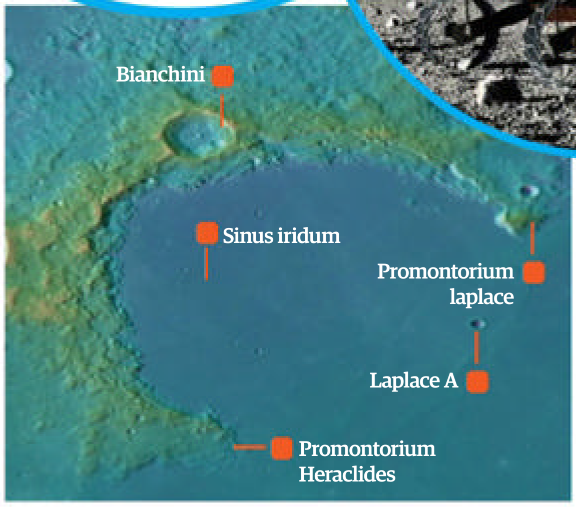


A popular destination

The Mare Imbrium is a 1,145-kilometre (711-mile)-wide diameter impact basin, formed about 3.8 billion years ago. Since then, it has been flooded with lava to form a large and relatively flat area, making it an ideal landing spot for manned and unmanned missions to explore the geology and formation of this region.

Lunokhod 1 visited in 1970, 250 kilometres (155 miles) south-west of Laplace A, and in the following year Apollo 15 landed near the Apennine mountain range on the south-eastern rim of the area.

China's Jade Rabbit was intended to land at Laplace A, near the boundary between Mare Imbrium and Sinus Iridum, the Bay of Rainbows, but ended up landing to the north-east of it, just south of Laplace F, a crater in the Mare Imbrium.



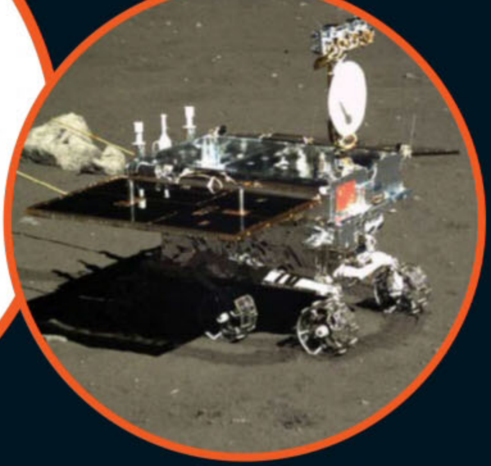
03

Jade Rabbit (Yutu)

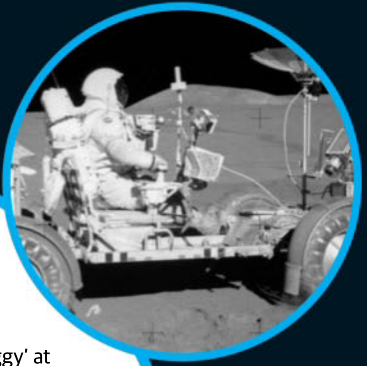
Country: **China**
Launch date: **01 December 2013**
Mass: **140kg (308lb)**

Yutu has a box-like body, with two large solar panels deployed on each side, providing power for its six cleated wheels. A suspension system allows it to drive over 20-centimetre (7.8-inch) obstacles and cope with 20-degree slopes. Despite being remote-controlled from Earth, it features autonomous navigation systems.

Its main objective was to survey the structure of the lunar surface using spectrometers and ground-penetrating radars, to develop the technology for the long-term Chinese Lunar Exploration Program. It managed to travel 100 metres (330 feet) and spent just over a month on the Moon taking photos and examining the soil, before several system failures stopped it moving on 25 January 2014.



04



Lunar Roving Vehicle

Country: **USA**
Launch date: **26 July 1971 (Apollo 15)**
Mass: **210kg (463lb)**

It took 17 months to design and build the 'Moon Buggy' at a cost of £25 million ($38 million). The four-wheel drive, electric-powered buggy was built to carry two astronauts and all their bulky lunar exploration equipment, plus life support systems. Special spacesuits that could bend at the waist were created so that the astronauts could sit in the buggy and it had a multi-function T-handle control that enabled either astronaut to steer, accelerate or stop the vehicle.

The 3.1-metre (10.2-foot) chassis was constructed of aluminium alloy tubing and it could carry a load of 490 kilograms (1,080 pounds), just over twice its own mass of 210 kilograms (460 pounds). Its average speed was around nine kilometres (5.6 miles) per hour and it could travel a maximum of 7.6 kilometres (4.7 miles) from the Lunar Module.

An onboard navigation computer kept track of where the buggy was in relation to the Lunar Module and a colour TV camera sent images back to Mission Control to provide additional navigation advice and directions.

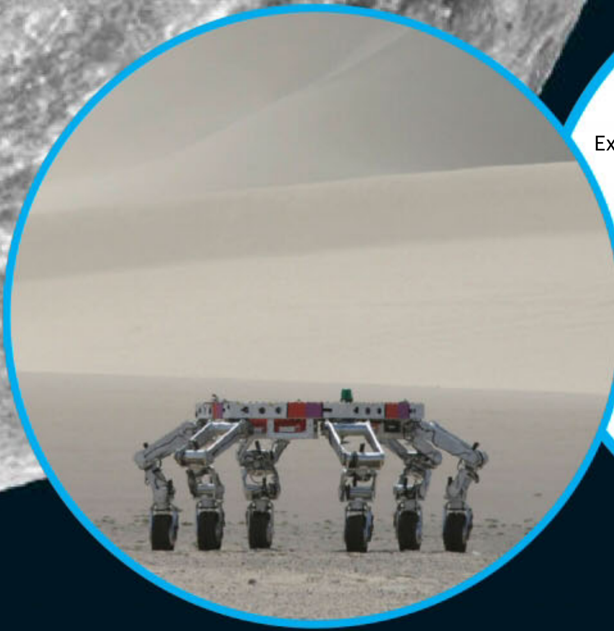
Moon buggies were successfully used to travel across the lunar surface by the Apollo 15, 16 and 17 Moon landing missions.

05

Athlete

Country: **USA**
Launch Date: **Prototype**
Mass: **850kg (1,873lb)**

The All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) looks like a shopping trolley gone wrong. The vehicle has six wheels that are fitted to adjustable limbs, so in obstacle-free terrains, it can easily run along. In extreme terrains it can straighten to a height of two metres (6.6 feet) enabling it to walk over obstacles. Prototypes were tested in 2005 with a view to using the concept to carry payloads on the Moon or Mars. Four years later, a second concept, the Tri-Athlete, with three-wheeled limbs was developed. They were intended to be used in pairs so that they could dock either side of a cargo pallet. In Earth gravity it could carry a load of 450kg (992lb) compared to the original's 300kg (661lb).



Mars explorers

Take a look at the anatomy of the toughest rovers on Mars

06

Spirit

Country: USA
Launch date: 10 June 2003
Mass: 185kg (408lb)

The six-wheeled Spirit rover carries a suite of scientific instruments including a rock abrasion tool and a microscope at the end of a its robotic arm, enabling the minute examination of Martian rock and soil samples. Mounted on top of a 1.5-metre (five-foot)-tall mast, its pair of panoramic cameras supply high-resolution, colour and stereo images of the terrain to help select areas to explore. The rover transmitted a total of 128,000 images of Mars back to Earth.

It carries navigation and hazard avoidance cameras as part of its auto-navigation system, allowing it to move independently and has a rocker-bogie suspension system to cope with 26-centimetre (ten-inch) obstacles.

Spirit has been unable to move since 2009 after it got stuck in some soft soil. A year later, NASA lost communication with the rover and it remains silent to this day.

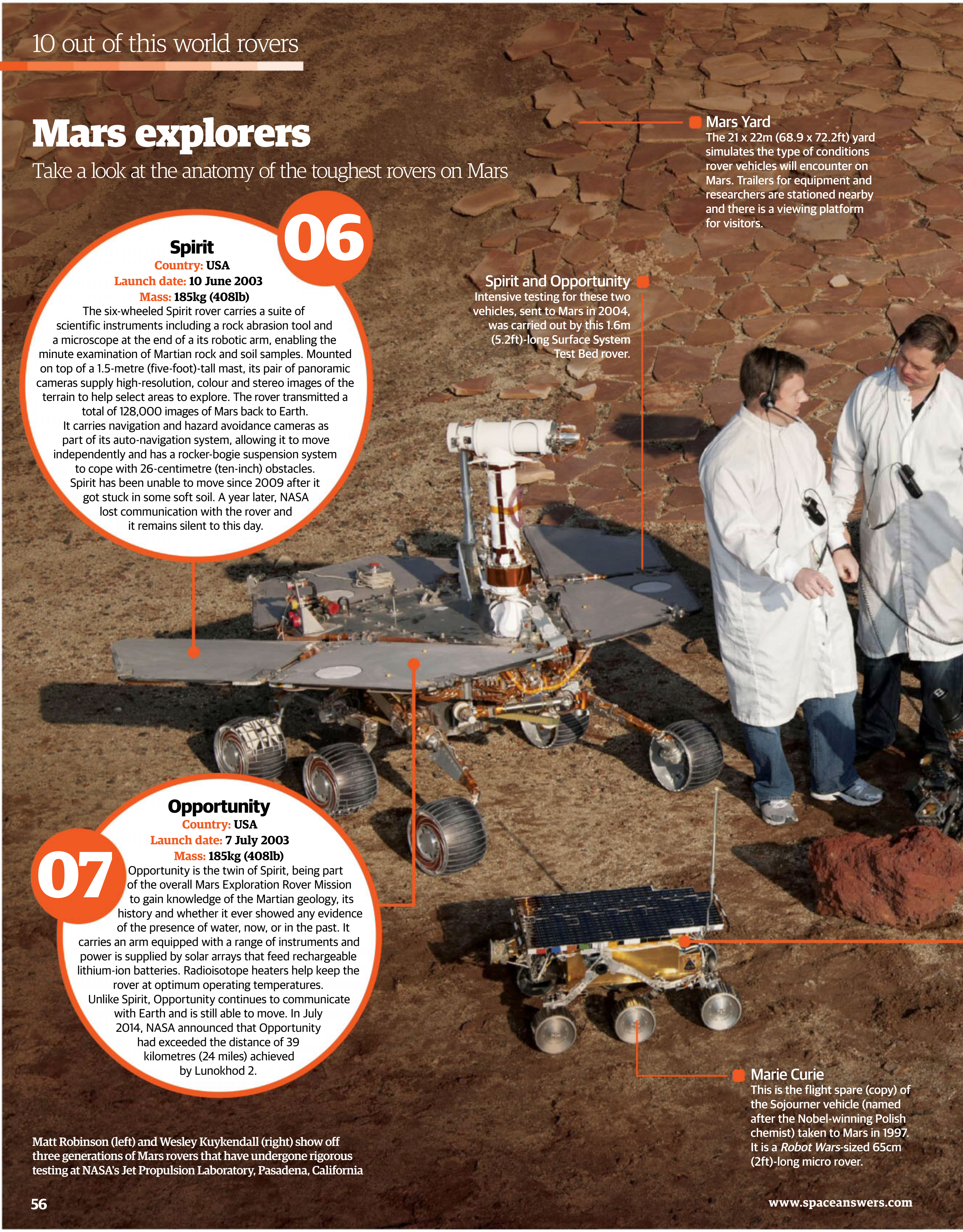
07

Opportunity

Country: USA
Launch date: 7 July 2003
Mass: 185kg (408lb)

Opportunity is the twin of Spirit, being part of the overall Mars Exploration Rover Mission to gain knowledge of the Martian geology, its history and whether it ever showed any evidence of the presence of water, now, or in the past. It carries an arm equipped with a range of instruments and power is supplied by solar arrays that feed rechargeable lithium-ion batteries. Radioisotope heaters help keep the rover at optimum operating temperatures.

Unlike Spirit, Opportunity continues to communicate with Earth and is still able to move. In July 2014, NASA announced that Opportunity had exceeded the distance of 39 kilometres (24 miles) achieved by Lunokhod 2.

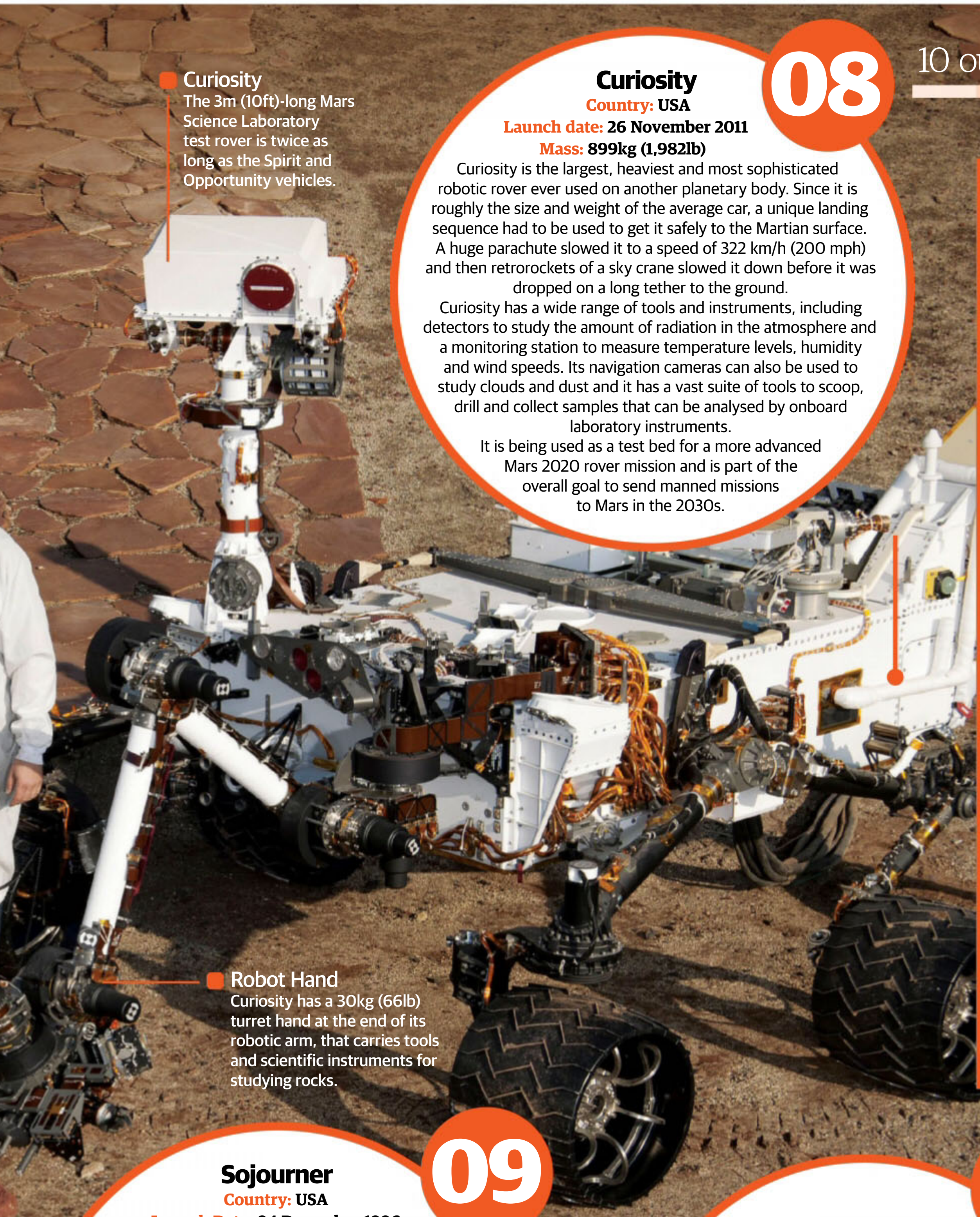


Mars Yard
The 21 x 22m (68.9 x 72.2ft) yard simulates the type of conditions rover vehicles will encounter on Mars. Trailers for equipment and researchers are stationed nearby and there is a viewing platform for visitors.

Spirit and Opportunity
Intensive testing for these two vehicles, sent to Mars in 2004, was carried out by this 1.6m (5.2ft)-long Surface System Test Bed rover.

Marie Curie
This is the flight spare (copy) of the Sojourner vehicle (named after the Nobel-winning Polish chemist) taken to Mars in 1997. It is a *Robot Wars*-sized 65cm (2ft)-long micro rover.

Matt Robinson (left) and Wesley Kuykendall (right) show off three generations of Mars rovers that have undergone rigorous testing at NASA's Jet Propulsion Laboratory, Pasadena, California



Curiosity
The 3m (10ft)-long Mars Science Laboratory test rover is twice as long as the Spirit and Opportunity vehicles.

Robot Hand
Curiosity has a 30kg (66lb) turret hand at the end of its robotic arm, that carries tools and scientific instruments for studying rocks.

08

Curiosity

Country: USA
Launch date: 26 November 2011
Mass: 899kg (1,982lb)

Curiosity is the largest, heaviest and most sophisticated robotic rover ever used on another planetary body. Since it is roughly the size and weight of the average car, a unique landing sequence had to be used to get it safely to the Martian surface. A huge parachute slowed it to a speed of 322 km/h (200 mph) and then retrorockets of a sky crane slowed it down before it was dropped on a long tether to the ground.

Curiosity has a wide range of tools and instruments, including detectors to study the amount of radiation in the atmosphere and a monitoring station to measure temperature levels, humidity and wind speeds. Its navigation cameras can also be used to study clouds and dust and it has a vast suite of tools to scoop, drill and collect samples that can be analysed by onboard laboratory instruments.

It is being used as a test bed for a more advanced Mars 2020 rover mission and is part of the overall goal to send manned missions to Mars in the 2030s.

5 cool things about Curiosity

It's a roving papparazzo

Curiosity carries a total of 17 cameras. The Mastcam features two sets of camera systems, one for moderate resolution the other for high-resolution images and video.

It has a powerful laser

ChemCam Uses a laser to zap rocks up to a distance of 7m (23ft) away. A high-resolution camera obtains detailed imagery of the rock and a telescope sends the light from the vaporised rock to three spectrographs to analyse its chemical composition.

It has a robot arm

Curiosity's arm has a reach of 2.1m (7ft) and three joints that are comparable to our shoulder, elbow and wrist joints.

It can ski

The cleated 50cm (20in)-diameter wheels on Curiosity are linked to a rocker-bogie suspension system that can cope with being tilted up to 45-degrees without overturning. The Curiosity rover has a top speed of 0.8km/h (0.5mph).

Radiation-powered

A radioisotope generator uses the heat from the decay of plutonium-238 to provide power to the rover and to keep its vital electronic systems warm.

09

Sojourner

Country: USA
Launch Date: 04 December 1996
Mass: 11.5kg (25lb)

Sojourner parachuted to the Martian surface on top the Carl Sagan Memorial Station lander, which deployed giant air bags to cushion the impact of the landing.

The micro rover looked like a coffee table with six 13-centimetre (5.1-inch)-diameter aluminium wheels attached to it. Its top speed was an ambling 0.4 metres (1.3 feet) per minute, but it could capably traverse obstacles and soft sand. The table top consisted of solar cells that produced up to 16 watts of power, while further power was supplied by a lithium-thionyl chloride non-rechargeable battery. Two monochrome cameras were mounted on its front and a colour camera on the rear of the vehicle.

It remained operational for 85 days, far exceeding its intended seven-day lifespan. It travelled a total of 100 metres (328 feet) and sent back 550 amazing images of the Martian surface.

10

Mars 2020 Rover

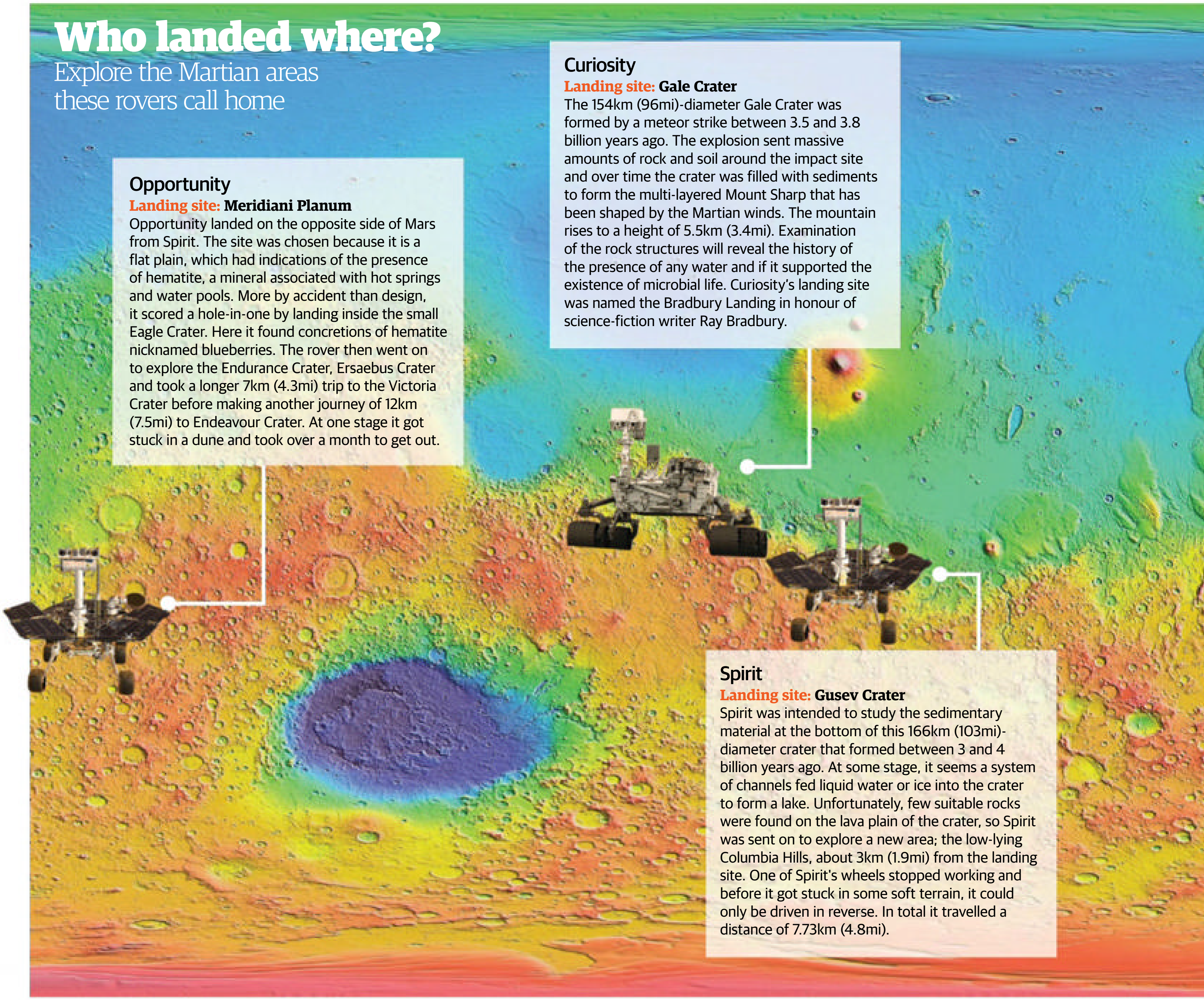
Country: USA
Launch Date: July/August 2020
Mass: Approx. 1,000kg (2,204lb)

Using the sky-crane landing technique to make a precise landing and much of the same hardware as the Curiosity rover, Mars 2020 will be an upgraded version of Curiosity. In light of Curiosity's findings it will test and use a new range of scientific instruments. It will continue to study chemical reactions and micro-structures to see if Mars ever supported life. In addition, it will obtain soil and rock samples with a view to being collected by future NASA missions.

In particular, it will examine the hazards presented by Martian dust storms and wind conditions to future human explorers. It will use experiments to see if it can produce oxygen from the carbon dioxide in the atmosphere for rocket fuel and human respiration.

Who landed where?

Explore the Martian areas these rovers call home



Opportunity

Landing site: Meridiani Planum

Opportunity landed on the opposite side of Mars from Spirit. The site was chosen because it is a flat plain, which had indications of the presence of hematite, a mineral associated with hot springs and water pools. More by accident than design, it scored a hole-in-one by landing inside the small Eagle Crater. Here it found concretions of hematite nicknamed blueberries. The rover then went on to explore the Endurance Crater, Ersaebus Crater and took a longer 7km (4.3mi) trip to the Victoria Crater before making another journey of 12km (7.5mi) to Endeavour Crater. At one stage it got stuck in a dune and took over a month to get out.

Curiosity

Landing site: Gale Crater

The 154km (96mi)-diameter Gale Crater was formed by a meteor strike between 3.5 and 3.8 billion years ago. The explosion sent massive amounts of rock and soil around the impact site and over time the crater was filled with sediments to form the multi-layered Mount Sharp that has been shaped by the Martian winds. The mountain rises to a height of 5.5km (3.4mi). Examination of the rock structures will reveal the history of the presence of any water and if it supported the existence of microbial life. Curiosity's landing site was named the Bradbury Landing in honour of science-fiction writer Ray Bradbury.

Spirit

Landing site: Gusev Crater

Spirit was intended to study the sedimentary material at the bottom of this 166km (103mi)-diameter crater that formed between 3 and 4 billion years ago. At some stage, it seems a system of channels fed liquid water or ice into the crater to form a lake. Unfortunately, few suitable rocks were found on the lava plain of the crater, so Spirit was sent on to explore a new area; the low-lying Columbia Hills, about 3km (1.9mi) from the landing site. One of Spirit's wheels stopped working and before it got stuck in some soft terrain, it could only be driven in reverse. In total it travelled a distance of 7.73km (4.8mi).

Timeline of a rover

Discover the exciting history of these rovers

Sojourner

4 July 1997

The first rover to be successfully operated on another planet. It was part of NASA's Mars Pathfinder project to test the viability of a Martian rover.

Sojourner

27 September 1997

Final transmission from the rover. During its operation it conducted over 15 chemical studies of rocks and sent back data about Martian weather.

Spirit

6 February 2004

Makes the first drill hole in a Martian rock using its Rock Abrasion Tool (RAT). The rock is analysed by its two spectrometers.

Spirit

5 March 2004

NASA announces that a rock called Humphrey indicates that it was of volcanic origin and might have contained water at some stage.

Opportunity

6 January 2005

Discovers the first meteorite on the Martian surface. Since then, Opportunity has encountered five similar iron-nickel meteorites.

Spirit

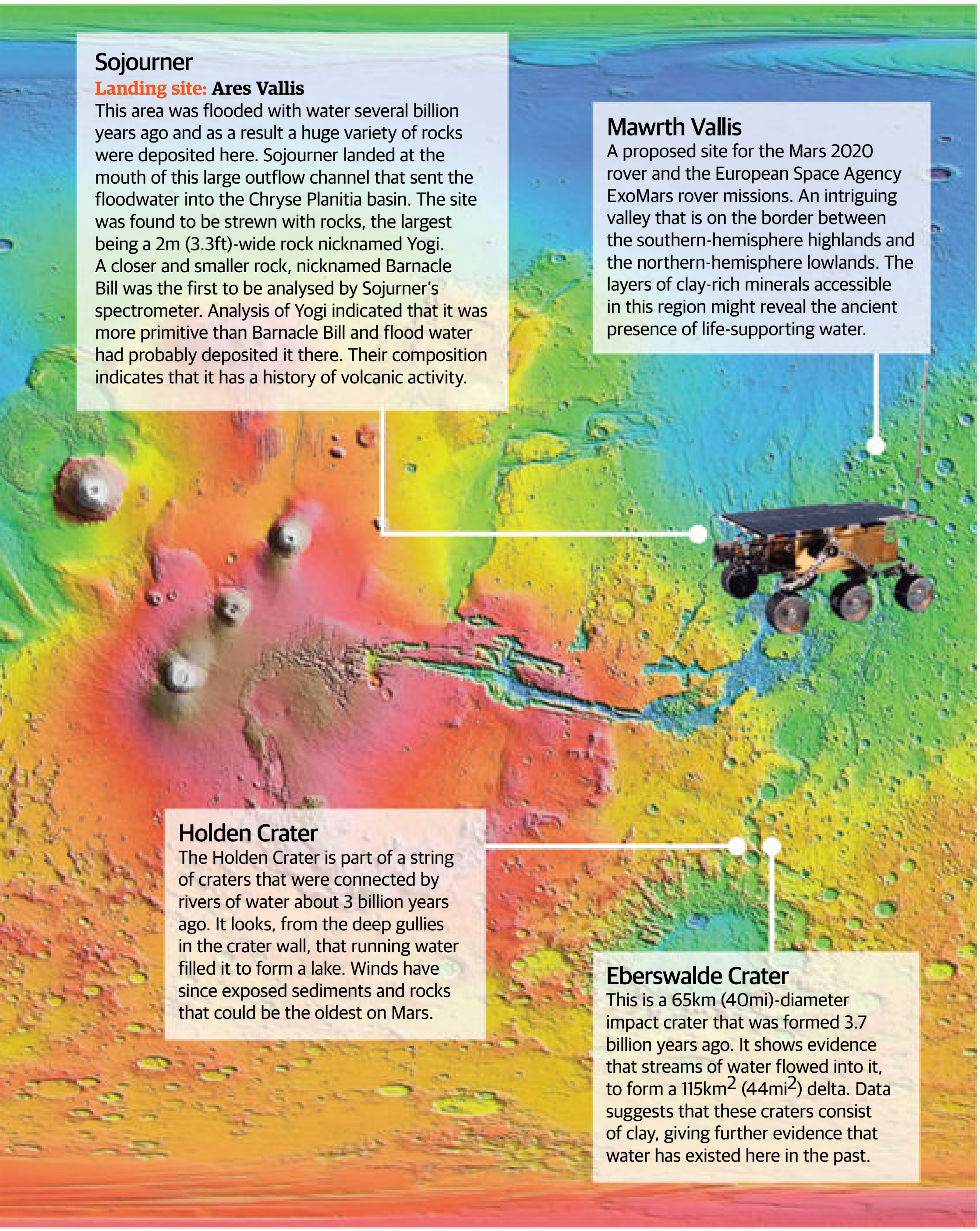
9 March 2005

Solar panels suddenly become 33% more efficient, cleaned by dust devils blowing over the surface. Dust devils are photographed by Spirit.

Opportunity

26 September 2006

At a distance of 7km (4.3mi) from its landing site, the rover arrived at the Victoria impact crater. It spent two years at this spot enduring severe dust storms.



Sojourner

Landing site: **Ares Vallis**

This area was flooded with water several billion years ago and as a result a huge variety of rocks were deposited here. Sojourner landed at the mouth of this large outflow channel that sent the floodwater into the Chryse Planitia basin. The site was found to be strewn with rocks, the largest being a 2m (3.3ft)-wide rock nicknamed Yogi. A closer and smaller rock, nicknamed Barnacle Bill was the first to be analysed by Sojurner's spectrometer. Analysis of Yogi indicated that it was more primitive than Barnacle Bill and flood water had probably deposited it there. Their composition indicates that it has a history of volcanic activity.

Mawrth Vallis

A proposed site for the Mars 2020 rover and the European Space Agency ExoMars rover missions. An intriguing valley that is on the border between the southern-hemisphere highlands and the northern-hemisphere lowlands. The layers of clay-rich minerals accessible in this region might reveal the ancient presence of life-supporting water.

Holden Crater

The Holden Crater is part of a string of craters that were connected by rivers of water about 3 billion years ago. It looks, from the deep gullies in the crater wall, that running water filled it to form a lake. Winds have since exposed sediments and rocks that could be the oldest on Mars.

Eberswalde Crater

This is a 65km (40mi)-diameter impact crater that was formed 3.7 billion years ago. It shows evidence that streams of water flowed into it, to form a 115km^2 (44mi^2) delta. Data suggests that these craters consist of clay, giving further evidence that water has existed here in the past.

Curiosity

27 August 2013

For the first time, it plotted a course and travelled a distance of 10m (33ft) using its navigation system. It uses software from Opportunity.

Curiosity

11 September 2014

Reaches Mount Sharp after travelling about 6.9km (4.3mi). This is its prime destination. Here it will investigate its surroundings.

Spirit

1 May 2009

The rover gets bogged down in soft soil and is no longer able to move. On 22 March 2010 it sent its last signals to Mission Control.

Opportunity

25 January 2014

The 10th anniversary of the rover's landing on Mars. Rock examinations indicated that Martian conditions were once suitable for microorganisms.

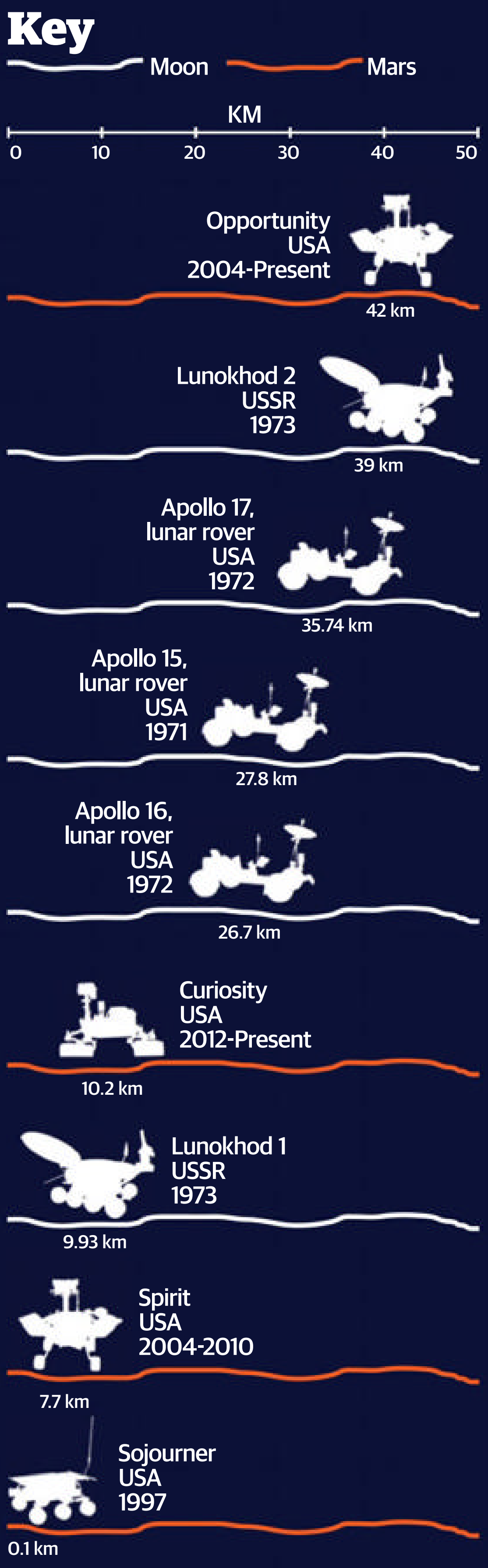
Curiosity

16 December 2014

NASA announces Curiosity detected spikes in methane gas levels in the atmosphere. This could indicate the presence of microbes.

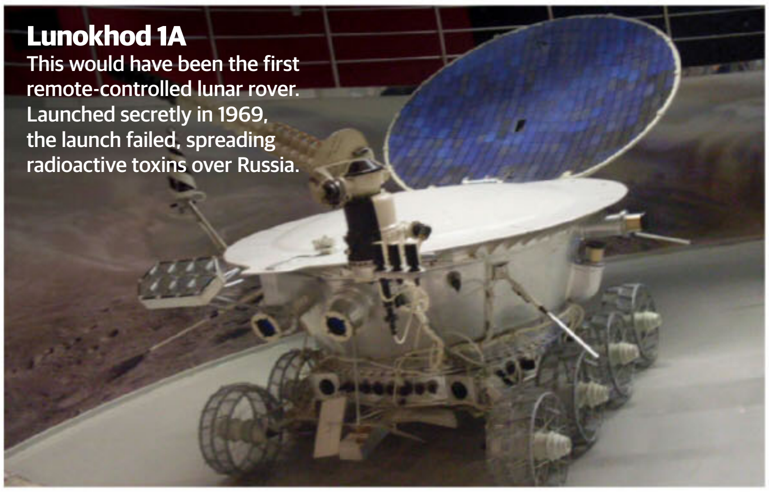
Roving records

Which rovers went the distance?

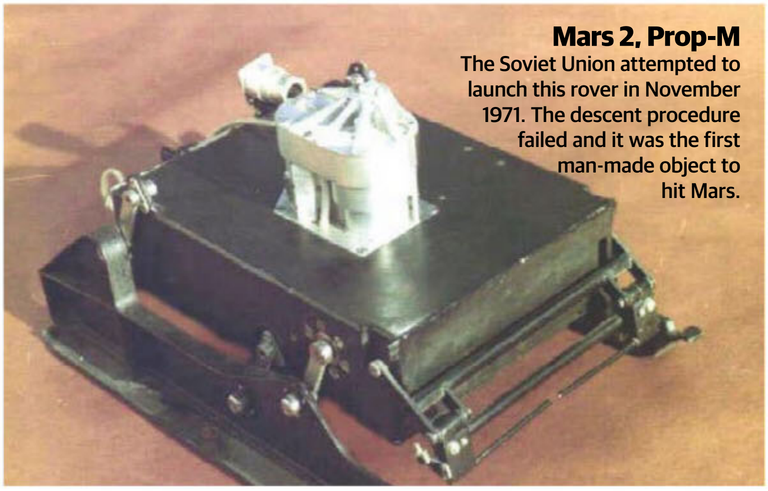


5 that didn't make it

Lunokhod 3
The fourth and last Lunokhod, it was intended for launch in 1977. Lack of funding meant that it ended up on display at the NPO Lavochkin museum.

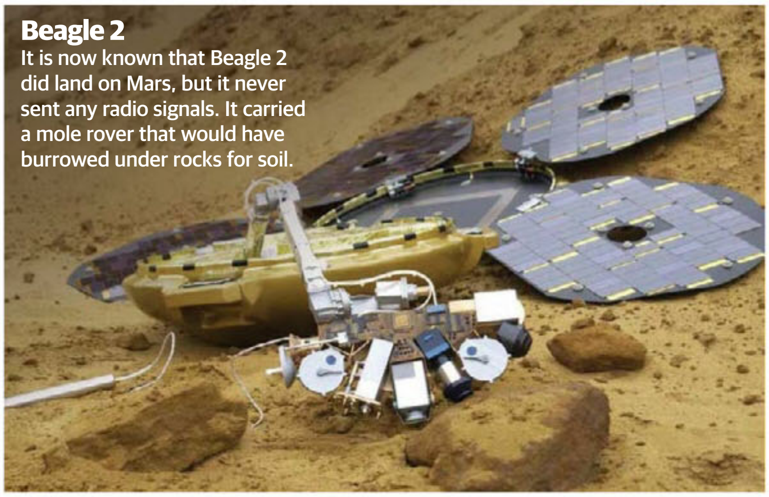


Lunokhod 1A
This would have been the first remote-controlled lunar rover. Launched secretly in 1969, the launch failed, spreading radioactive toxins over Russia.



Mars 2, Prop-M
The Soviet Union attempted to launch this rover in November 1971. The descent procedure failed and it was the first man-made object to hit Mars.

Mars 3
This was another attempt to put a Prop-M rover on Mars. On 2 December 1971 it landed on Mars, but due to intense dust storms, radio signals stopped.



Beagle 2
It is now known that Beagle 2 did land on Mars, but it never sent any radio signals. It carried a mole rover that would have burrowed under rocks for soil.

Astronaut Harrison Schmitt scoops samples of lunar dust and rock during the Apollo 17 mission to the Moon in 1972

© NASA

5 AMAZING FACTS ABOUT

Moon dust

You shouldn't breathe it

Following a lunar walk, astronaut Harrison Schmitt noted the smell of Moon dust in the air, like gunpowder. NASA pathologist Russell Kerschmann warned that prolonged exposure to Moon dust could seriously damage human lungs.

It wears through spacesuits

Moon dust is very abrasive and clingy. Apollo 17 astronauts had problems moving their arms properly because lunar dust had clogged up the joints, while it wore through three layers of Kevlar-like armour on Harrison Schmitt's Moon boot.

It's magnetic

Because tiny specks of iron are present in the glass shell of each lunar dust particle, magnets can be used to filter the dust out of the air and off sensitive equipment. The dust that makes up lunar soil can also be quickly microwaved into flat sheets, meaning roads and landing pads can easily be created for future missions.

It's actually mostly glass

Lunar dust is mostly made up of very fine particles of silicon dioxide glass, plus iron, calcium and magnesium, as well as other trace minerals. It's all been shattered and ground into a fine powder over billions of years of meteorite impacts.

Astronauts have tasted it

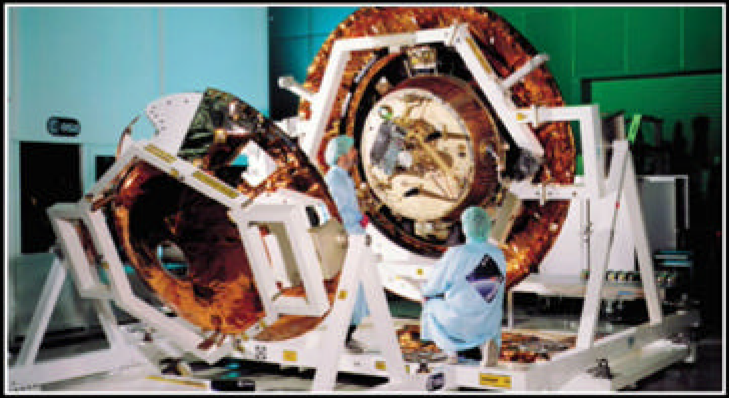
In the interests of science (as well as pure human curiosity), Apollo astronauts have touched, smelled and even tasted Moon dust. Apparently, it's as fine as flour but abrasive, plus it both smells and tastes like gunpowder. It's also clingy and hard to brush off.

Landing on Titan

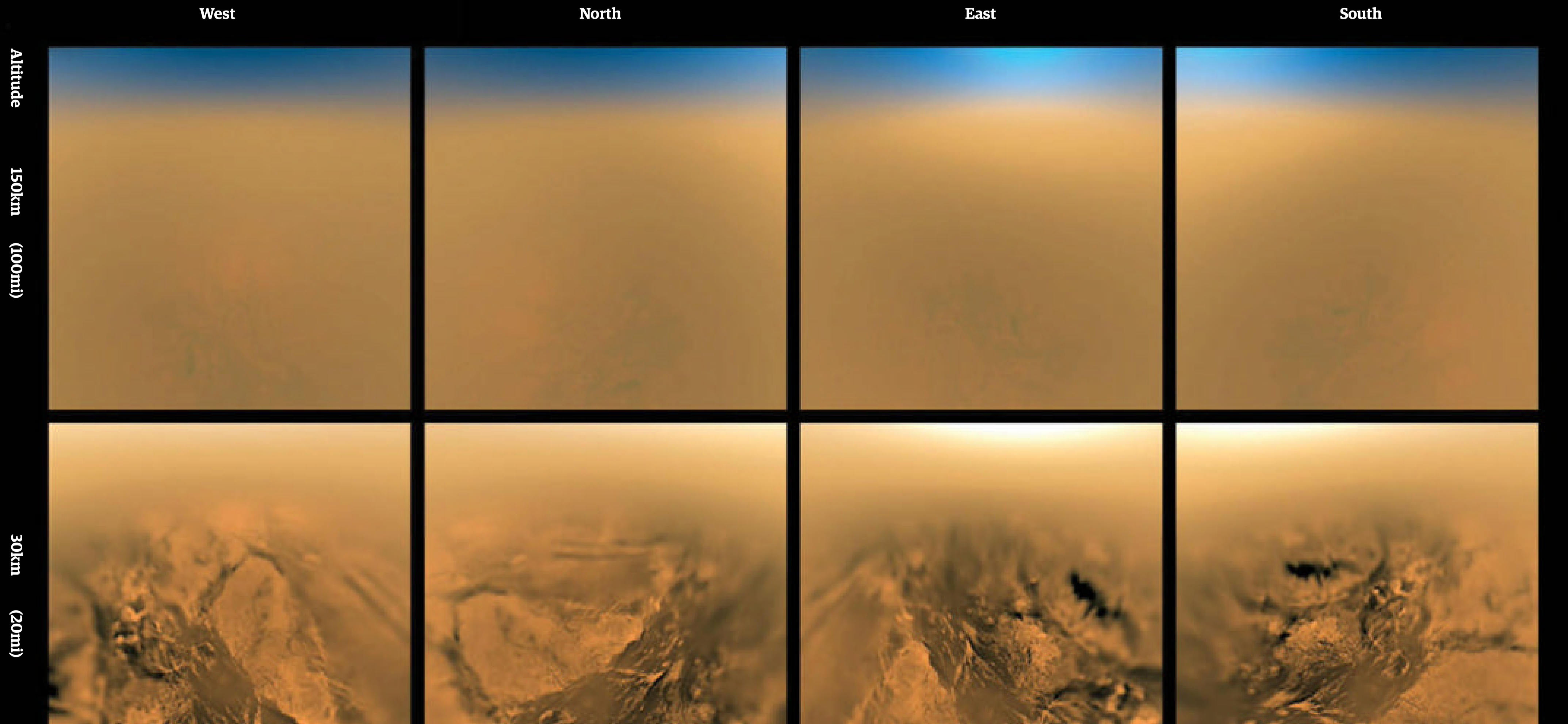
Celebrating the 2015 tenth anniversary of the Huygens probe's descent to the surface of Saturn's giant moon

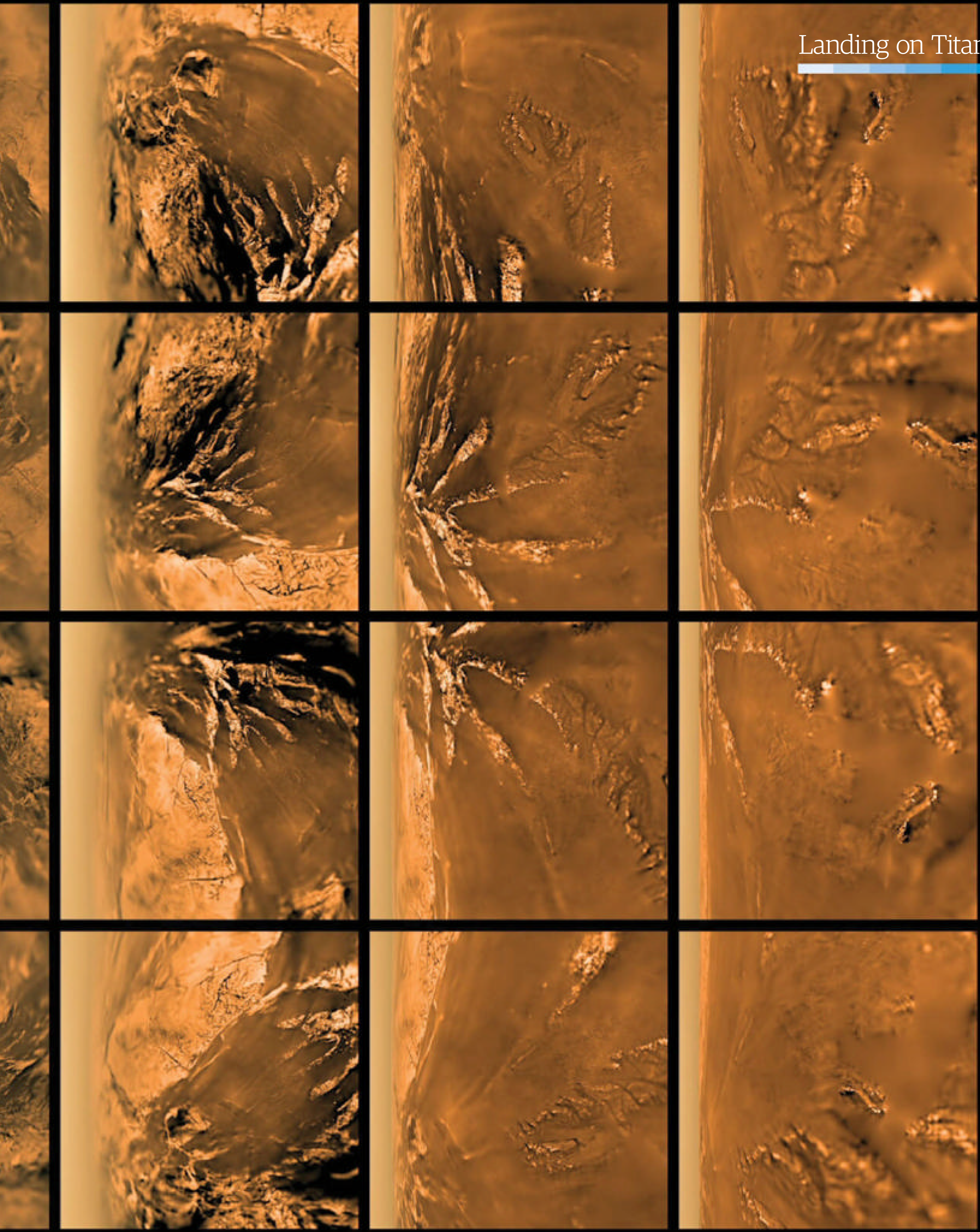
Just over a decade ago, on 14 January 2005, the European Space Agency's Huygens probe separated from NASA's Cassini orbiter around Saturn, and began its descent onto Titan. Although it only transmitted data from the surface for 72 minutes before losing contact with Cassini, and a problem with its programming meaning half the images and data it received was lost, Huygens was still considered a huge success. It's the only successful soft landing on a world in the outer Solar System, the images returned are the first taken from a surface in the outer Solar System, and Huygens remains the most distant landing of any man-made spacecraft today.

The images taken here showed, for the first time, what was beneath the impenetrable yellow haze of Titan's dense nitrogen atmosphere: a relatively smooth surface with a few mountains and ice volcanoes, plus lakes of liquid hydrocarbons in the moon's chilly average temperature of around -180 degrees Celsius (-292 degrees Fahrenheit).



The Huygens descent module is seen here being tended to by two ESA scientists. The huge copper disc at the front is the vital front shield, which protected Huygens from the blistering heat of atmospheric entry





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Ancient stellar encoutner

A red dwarf passed within 0.8 light years of our Sun 70,000 years ago. **All About Space** caught up with the star's discoverer to find out what kind of havoc this wanderer caused in the Solar System

Interviewed by Gemma Lavender

INTERVIEWBIO

Dr Ralf-Dieter Scholz

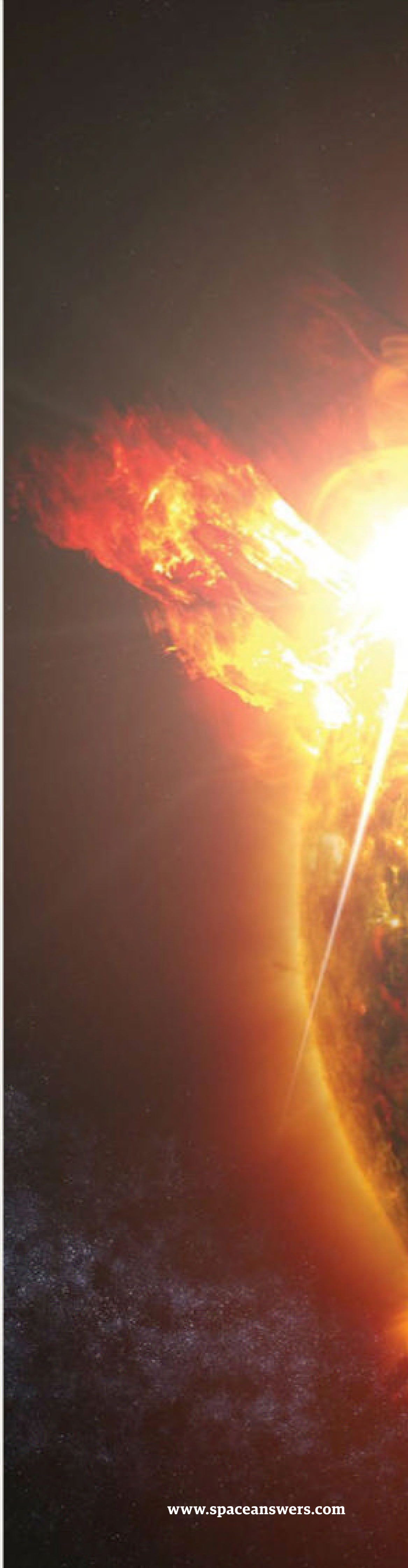
Discoverer of Scholz's star, a red dwarf with a brown dwarf companion, Ralf-Dieter Scholz is an astronomer based at the Leibniz Institute for Astrophysics Potsdam (AIP) in Germany where he researches stars (such as hypervelocity and those in clusters) in our galaxy as well as the mysterious gaseous objects known as brown dwarfs.

Could you tell us a bit about how you came to find Scholz's star?

It was a continued search for nearby stars. I have been doing this for around 20 years now. What I should mention, by the way, is that the solar neighbourhood is not very well known. In 1997 it was estimated that around 30 per cent of stars are hiding within around 32 light years of us. There are many nearby stars and also brown dwarfs that are missing or hiding even.

In the case of Scholz's star, I started to search in an area that quickly became problematic because there was a lot of crowding and many stars overlapped in images I had of the galactic plane of the Milky Way. In my search, I got close to the galactic plane, around two degrees, which is very close. The other thing I concentrated on was the movement of stars as observed from the Solar System. In our search for nearby stars, we should be observing their motion. Astronomer Edmond Halley, who discovered Halley's Comet should be much more famous for his discovery of the movement of Sirius, the brightest star in Earth's sky. I think his finding of Sirius' motion is a much more important discovery for astronomy than the comet. This is because it became immediately clear that stars are not actually fixed in the sky, they are at different distances from us and it is only logical to expect that the more they move, the closer they are.

This is the principal I used but I have also applied new observations and new databases in my search for nearby stars, including Scholz's star. My job is that of a more traditional astronomer, taking advantage of lots of available data. Data mining is also a term astronomers use in this respect.



Just like red dwarf Proxima Centauri, Scholz's star is thought to be a flare star. These undergo unpredictable and often dramatic increases in brightness

Scholz used data from the Wide-field Infrared Survey Explorer (WISE) satellite - seen here with an engineer loading hydrogen gas into the spacecraft at the Vandenberg Air Force Base, California

Scholz's star's discoverer Ralf-Dieter Scholz believes that if the star has disturbed any comets from the Oort Cloud, then we won't know for at least 100,000 years

"Scholz's star could have also touched the outer Oort Cloud and directed the comets to different orbits"

My search for Scholz's star was a combined search for star motion and colour. I didn't really want to find sun-like stars, which are yellow dwarfs, so to speak. My main aim was to discover red or brown dwarfs. With this in mind, I used a sample of very bright sources and selected a particular colour spectrum of stars, which were observed by NASA's Wide-Field Infrared Survey Explorer (WISE) satellite. I only really expected to find dwarf stars of spectral type M5, a very cool, main-sequence red dwarf. I had to use the motion of the stars to exclude the presence of any background stars, which may have been nearby red M-dwarfs that do not move in the sky.

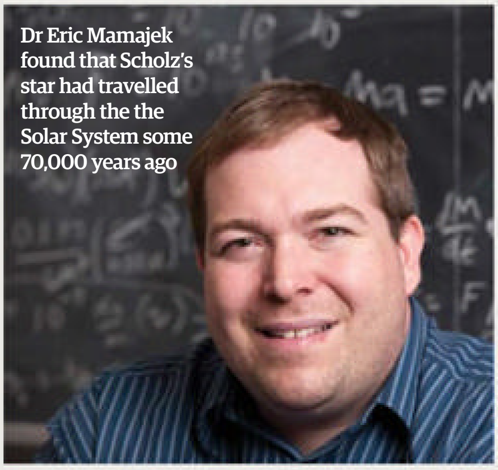
But what I found instead was a late red dwarf of spectral class M9, which rests on the boundary of the brown dwarf region and this was just based on my measurements of the high intensity radiation that it was throwing out. This spectral type is known to be quite rare and there is only one other nearby object, known as LP 944-20, located 21 light years from the Solar System in the constellation of Fornax. I also worked out that Scholz's star could quite possibly be part of a binary. I originally thought that the binary was comprised of two red dwarfs that were equal in mass but I soon discovered I was wrong.

How do we know that Scholz's star has a brown dwarf companion?

Another team of scientists confirmed the spectral type of Scholz's companion. They believed that it should be an M9 dwarf and a mid T-class brown dwarf companion, which have temperature ranges of 430 to 1,030 degrees Celsius (806 to 1,886 degrees Fahrenheit). As well as the indication of spectra, they also confirmed the pairing through adaptive optics imaging and because it is a very close binary, it could now be seen. The two independent conclusions prove that Scholz's star is in a binary. There are also two other binaries comprised of a late M-dwarf and a T5 brown dwarf.

Roughly where in the Solar System did Scholz's star pass through?

There is a 98 per cent probability that the star crossed the Solar System. It was in the Solar System for around 10,000 years, from 65,000 to 75,000 years ago. The closest point was about 70,000 years ago at a distance of 0.8 light years away from Earth. Scholz's star passed through the outer Oort Cloud, not the inner one which would have been much more dangerous for us or a more important one for comets, with respect to them being



Dr Eric Mamajek found that Scholz's star had travelled through the the Solar System some 70,000 years ago

sent through our Solar System. Scholz's star could have also touched the outer Oort Cloud and directed the comets to different orbits, but they will take hundreds of thousands or millions of years to even come close to us in any case.

Would any Earth-based observers have been able to see Scholz's star?

Personally, I think not. The star is much fainter than you would expect to see with the naked eye. I mean, even if Proxima Centauri, our closest red dwarf, which is a bit hotter than Scholz's star, came as close to us as Scholz's star did, you still wouldn't be able to see it with the naked eye. I mean, by the naked eye, it is harder to see because it would be at a magnitude of 11. And we can see stars only up to a magnitude of six with the naked eye. Nonetheless, Scholz's star is a strong flare star and outbursts from its surface can be very strong.

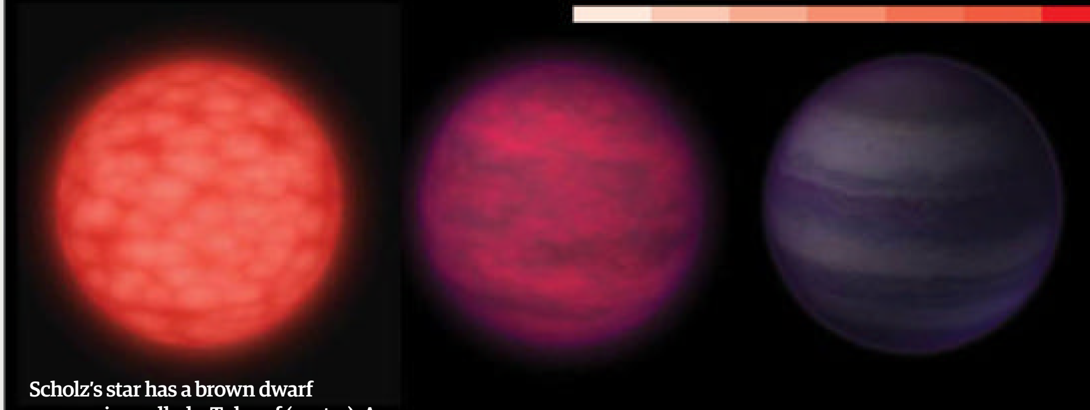
Flare stars can reach up to seven or eight magnitudes. So in that case, of course, it could be visible, but who would notice? [laughs]. If Scholz's star was still on the boundary of sixth magnitude, at normal times it would be easier to observe by the naked eye. There was also no pollution 70,000 years ago and Earth had very clear skies where you could see more stars in the Milky Way during the night and they would appear very clearly if you were to observe them.

Will the star be back?

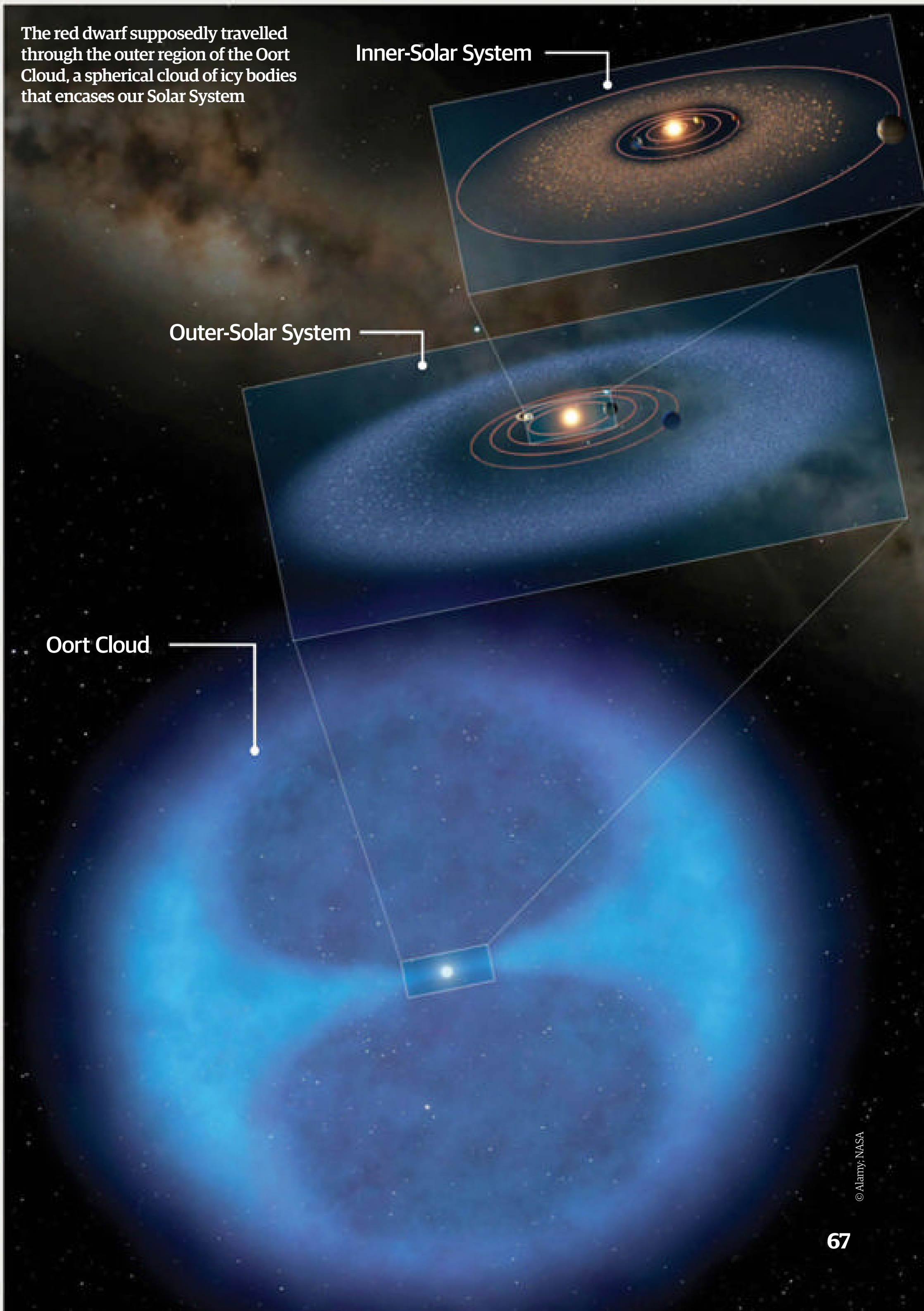
I don't think so because it is on a rather eccentric orbit. The stars move more or less in the spiral arm on a circular orbit around the galactic centre, whereas this star crosses close to the Sun at a speed of 80 kilometres per second (50 miles per second) and is also moving on a very different orbit to other stars. It changes its distance and comes close to the galaxy's central region as it crosses the solar neighbourhood region but I would not expect it to return. It will not come anywhere near the Sun again.

Where is Scholz's star at the moment?

It is about 20 light years from us. Astronomers have been observing the star recently and they were able to see it with their own telescopes. There are a few videos on YouTube where some guys have observed it. You don't really need a large telescope to see Scholz's star, as long as you are not looking to observe it in any real visual detail, but with the help of a CCD camera and at least an eight inch telescope it is really easy, as this is usually the limit that amateurs have. ●



Scholz's star has a brown dwarf companion called a T-dwarf (centre). A T-dwarf is cooler than an L-type (left) and Y-type brown dwarf (right)



The red dwarf supposedly travelled through the outer region of the Oort Cloud, a spherical cloud of icy bodies that encases our Solar System

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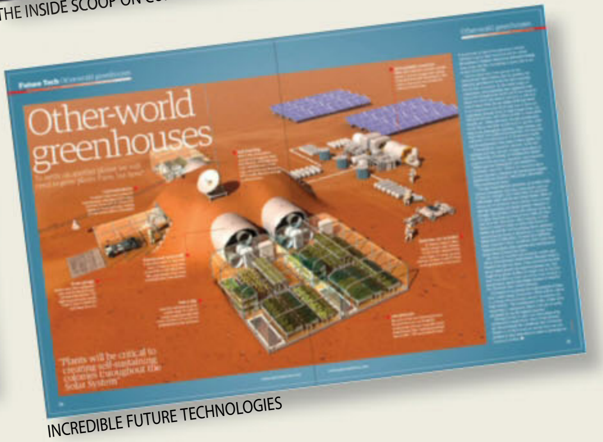

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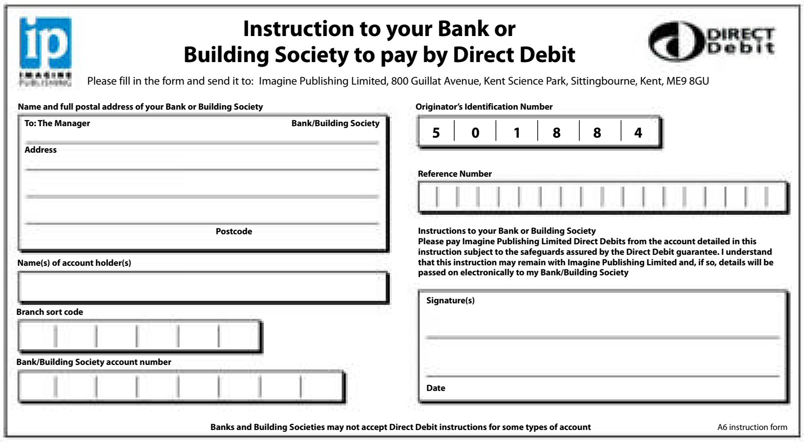

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YOUR QUESTIONS ANSWERED BY OUR EXPERTS

In proud association with the National Space Centre *www.spacecentre.co.uk*

Sophie Allan

National Space Academy education officer

- Sophie studied Astrophysics at university. She has a special interest in astrobiology and planetary science.

Zoe Baily

National Space Centre

- Zoe holds a Master's degree in Interdisciplinary Science and loves the topic of space as it unites different disciplines.

Josh Barker

Education team presenter

- Having earned a Master's in Physics and Astrophysics, Josh continues to pursue his interest in space at the National Space Centre.

Gemma Lavender

Senior Staff Writer

- Gemma has been elected as a fellow of the Royal Astronomical Society and is a keen stargazer and telescope enthusiast on **All About Space** magazine.

SPACE EXPLORATION

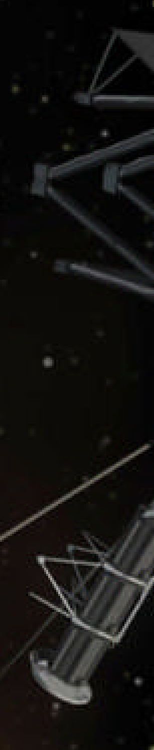
How far can we send a spacecraft before we lose contact with it?

Ralf Watts

This distance actually changes with improving technology. Spacecraft like Voyager 1, which is over 19 billion kilometres (12 billion miles) away, use something called the Deep Space Network of three radio telescope sites to communicate with Earth.

Using these huge radio antennae networks - the largest dishes are 70 metres (230 feet) in diameter - in Australia, Spain and California we can communicate with distant spacecraft. However, low-power transmitters on space missions mean that by the time information arrives from the outer planets, the signal power is 20 billion-times lower than that in a typical wristwatch battery.

By increasing the size and spread of the radio antennae, a weaker signal can be processed, but with the current space network, Voyager 1 has about ten years before the limit is reached. **SA**



ASTRONOMY

Why can't I see red dwarf stars with the naked eye?

Luis Bower

Red dwarfs, which are small and relatively cool stars in comparison to our Sun, are not readily detectable by the naked eye since they have low temperatures and are low in brightness. It's actually quite surprising that they are not so easy to detect since they make up a good three-quarters of our galaxy's star population.

The closest red dwarf to Earth is Proxima Centauri, which rests 4.24 light years away, in the constellation Centaurus. At a magnitude of +11.05, this star is difficult to see with the naked eye and you would need an optical aid like a decent pair of binoculars or a telescope to be able to spot it. **GL**

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The Deep Space Network (inset) communicates with the Voyager 1 spacecraft

DEEP SPACE

How do intergalactic and extragalactic space differ from each other?

Hannah Green

Although we can use both intergalactic and extragalactic to describe areas of space, they do have slightly different definitions. In general we use the word intergalactic when talking about a place in the universe that is located somewhere between two or more galaxies. In comparison to this we can use the word extragalactic to describe anything that can be classified as being outside of the galaxy we reside in, the Milky Way. **ZB**

DEEP SPACE

Why don't all galaxies have spiral arms?

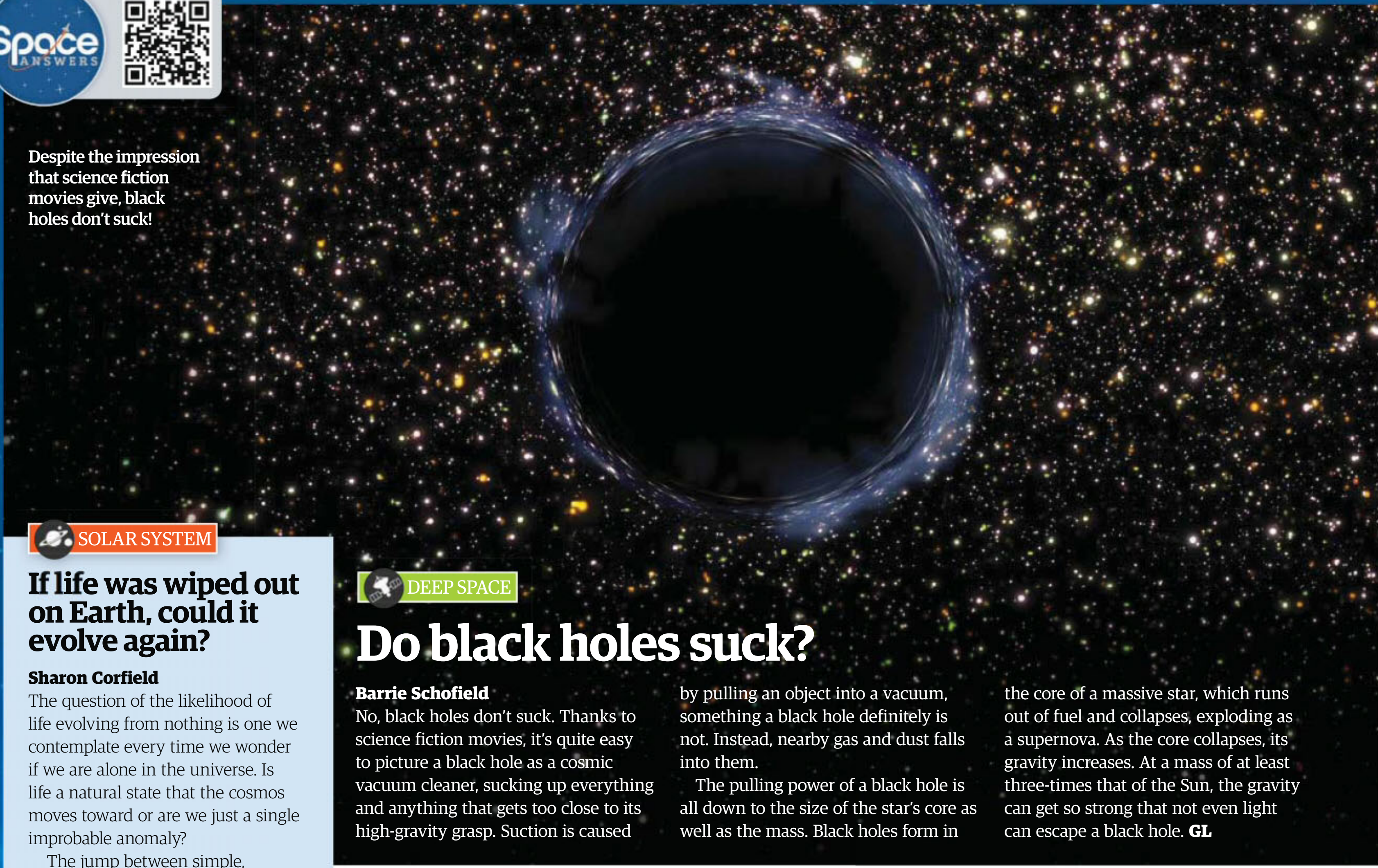
Jasmine Beck

Galaxies with twisting spiral arms are the most common type in the universe but are not the only kind of galaxy.

Elliptical galaxies are spheroid shaped galaxies with little internal structure. They are thought to form through the collision of two or more galaxies. Lenticular galaxies are somewhat more defined and tend to have a thin disc shape, but both lack spiral arms.

It is thought the arms in spiral galaxies form as a result of giant molecular clouds of hydrogen within a rotating galaxy. For a spiral shape to emerge it is thought that perturbations within the matter of the galaxy cause density waves to form. This means that stars swirling in the galaxy disc bunch up at certain points and create these stationary-looking structures, much like cars in traffic jam. **ZB**

Approximately 60 per cent of spiral galaxies contain multiple arms



Despite the impression that science fiction movies give, black holes don't suck!

DEEP SPACE

Do black holes suck?

Barrie Schofield

No, black holes don't suck. Thanks to science fiction movies, it's quite easy to picture a black hole as a cosmic vacuum cleaner, sucking up everything and anything that gets too close to its high-gravity grasp. Suction is caused by pulling an object into a vacuum, something a black hole definitely is not. Instead, nearby gas and dust falls into them.

The pulling power of a black hole is all down to the size of the star's core as well as the mass. Black holes form in the core of a massive star, which runs out of fuel and collapses, exploding as a supernova. As the core collapses, its gravity increases. At a mass of at least three-times that of the Sun, the gravity can get so strong that not even light can escape a black hole. **GL**

SOLAR SYSTEM

If life was wiped out on Earth, could it evolve again?

Sharon Corfield

The question of the likelihood of life evolving from nothing is one we contemplate every time we wonder if we are alone in the universe. Is life a natural state that the cosmos moves toward or are we just a single improbable anomaly?

The jump between simple, universal chemistry to complex life is complicated and there are a few leaps that seem potentially unlikely. However, research has shown that some aspects, such as the natural formation of complex organic molecules essential for life, can happen naturally and may be more inevitable than we first thought.

Right now though, there is still much debate but if we discover life outside of Earth we will be much more confident in answering this question. It would indicate that life is more than likely inevitable and would be able to evolve again. **ZB**

Earth is the only planet we know of that harbours life

DEEP SPACE

What are the dark shapes in the Orion Nebula?

Barrie Schofield

These are protoplanetary discs, pancakes of dust and gas around young stars, which make up planets, located some 1,500 light years away from Earth.

These discs are made mostly of gas but even a small amount of dust is able to make the discs appear opaque and dark at the wavelengths visible to the human eye. The discs also appear dark because they are silhouetted against the bright backdrop of hot gas, which comprises the famous star-forming region.

There's usually a red glow to be seen at the centre of these discs, which is a newly-formed star, roughly 1 million years old and can be anywhere from 30 to 150 per cent of the mass of the Sun. **GL**

Protoplanetary discs can be seen when you zoom into Hubble images of the Orion Nebula

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Jill Tarter, the former Director of the SETI (Search for Extraterrestrial Intelligence) Institute stands in front of the Allen Telescope Array, a radio telescope array dedicated to astronomical observations and the search for extraterrestrial intelligence

SPACE EXPLORATION

Could any extraterrestrial civilisation be aware of us?

Sam Lee

We have been broadcasting radio signals since the beginning of the 20th century. It is thought that any civilisation with advanced technology within 78 light years of Earth would be able to pick up on this leaked radiation.

Extraterrestrial civilisations might have difficulty making use of any signals they detect. For example, TV signals would be too weak to make images from and even if they could pick up signals, extraterrestrials would not understand human languages.

If these alien civilisations launched an array of optical telescopes into space, they might be able detect the presence of ozone in our planet's atmosphere. This might indicate to extraterrestrials that life forms are present on Earth and they are not alone. **GL**

ASTRONOMY

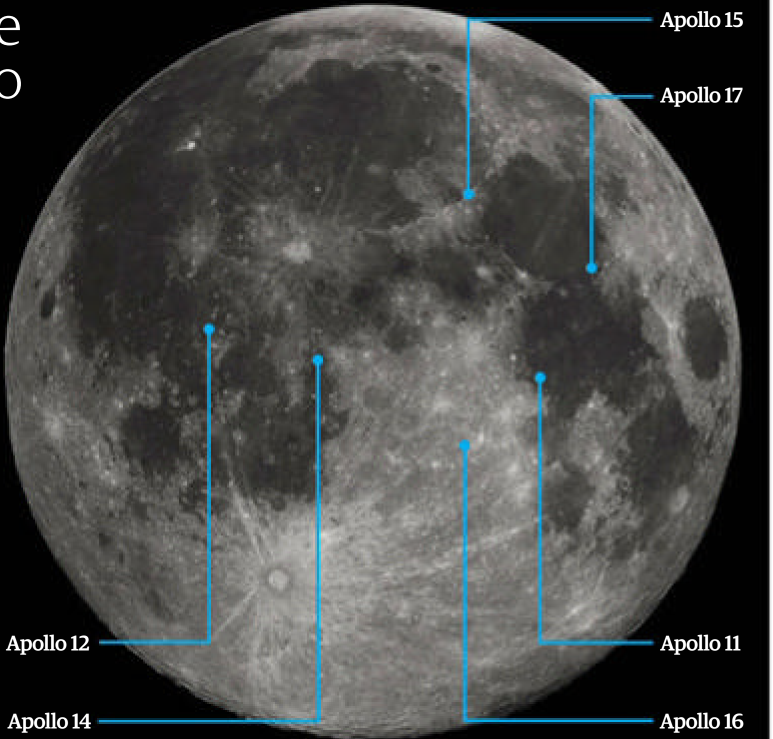
What size telescope would I need to see the different Apollo landing sites?

Shane Clews

The small size of the Apollo landing craft would mean an extremely large telescope would be needed. One of the best visible light telescopes available to us is the Hubble Space Telescope (HST). It is the largest telescope sent into space and also has the advantage of being slightly closer to the Moon than us on the surface.

Despite this, the HST does not have the necessary resolution to image the landing sites. The telescope would need to have over ten-times its current resolution power to achieve this. This is why the first images of the landing sites were only obtained a few years ago following the launch of the Lunar Reconnaissance Orbiter. This satellite was designed to take images of the surface of the Moon in very high resolution. **JB**

You would need an extremely large telescope to pinpoint the exact location of the Apollo landing sites



Quick-fire questions

@spaceanswers

Who was the youngest person to fly in space?
Soviet cosmonaut Gherman Titov was the youngest person to enter space. He was 25 years old when he flew the Soviet space mission Vostok 2, which was launched in August 1961.

What is Saturn's atmosphere made of?
Saturn's atmosphere is made mostly of hydrogen and helium along with traces of water ice and methane gas.

What is adaptive optics?
This is a technology that improves the performance of telescopes. The turbulence of Earth's atmosphere can make objects distorted and so a deformable mirror is used to compensate for these distortions.

What is a syzygy?
This is when three or more astronomical bodies, in a gravitationally-bound system, are roughly aligned in a straight line.

Is the Sun actually yellow?
It might be referred to as a yellow dwarf, but our Sun is in fact white in colour.

Which is the largest constellation across both hemispheres?
Consisting of 17 primary stars and spanning approximately 1,300 square degrees of the sky, Hydra, The Water Snake is the largest constellation we have discovered.

Does the Sun rotate?
The Sun does rotate, but not all at the same rate. The Sun's equator takes about 24 days to rotate, but at the poles, can take anything up to 36 days.

Can planets explode?
While some planets have boiling cores, this is not enough to cause a world to shatter let alone suddenly explode.

Quick-fire questions

@spaceanswers

Is there internet access on the International Space Station?

Yes, since January 2010 astronauts have had direct access to the internet on the ISS. Before, their tweets, emails and messages had to be sent via the Mission Control Center in Texas, USA.

What are Cepheid variables?

These are luminous stars, which change in brightness by expanding and contracting. The changes in luminosity are so regular that astronomers can use them to measure distances.

What does the constellation Orion represent?

Orion is named after the hunter in Greek mythology, who was said to be placed among the stars by Zeus. The Orion's Belt asterism is one of the most recognisable features in the night sky, making the constellation easy to locate.

Could we artificially make a black hole?

To make a black hole would mean compressing a large amount of matter and energy into a small amount of space. In practical terms, this is incredibly difficult.

Why don't we see the other side of the Moon?

The Moon makes one revolution around the Earth about every 27.3 days. However, the Moon also completes one full rotation on its axis in this time, so we always see the same side.

What was the first satellite sent into space?

Sputnik 1, which was the Soviet Union's first artificial satellite, was also the first spacecraft to be sent into space on 4 October 1957, fuelling the Space Race between the USA and the USSR.

The true edge of the Solar System stretches beyond the Kuiper belt

SOLAR SYSTEM

How big is the Solar System?

Liam Knowles

This really depends on what you class as the Solar System. The distances involved are enormous so we work in Astronomical Units (AU), where one AU equals 150 million kilometres (93.2 million miles) and is the distance between the Earth and Sun. Meanwhile, ice giant Neptune orbits at a distance of around 30AU. Beyond this orbit we have the Kuiper belt, which contains dwarf planets such as Pluto and stretches out to a distance of about 50AU.

The true edge of the Solar System is defined by where the Sun's gravity dominates and everything can be considered to orbit it. This rests beyond the Oort cloud, a sphere of icy objects at a distance of 100,000AU. To escape the dominance of the Sun's gravity you would need to travel past this point. **SA**

Manned missions such as the Space Shuttle avoided the Van Allen Radiation Belts

SPACE EXPLORATION

Can manned spacecraft survive the Earth's radiation belts?

Sam Ridge

Provided the right shielding is put in place, astronauts are able to survive the effects of our planet's Van Allen Radiation Belts, the doughnut-shaped regions that encircle our Earth, containing high-energy electrons and ions trapped in its magnetic field.

If it can be avoided, many of the manned missions up until now, such as the Space Shuttle, have stayed well below the altitude of the belts. According to radiation measurements taken by NASA's Explorer 1 spacecraft, which was launched in 1958, safe flight can occur below altitudes of 560 kilometres (350 miles) or so.

During the 1960s, bacteria and blood samples were sent into space and small animals were exposed to radiation by researchers at NASA as well as the Tower Shielding Facility in Oak Ridge, Tennessee, to investigate the effects of this radiation. **GL**

ASTRONOMY

What is an apochromatic telescope?

James Beed

An apochromatic telescope has a multi-lens setup to eliminate chromatic aberration when stargazing. Chromatic aberration is caused by the difference in wavelength of various colours of light. In a single-lens setup, blue light is focussed closer to the lens and it has a shorter focal length. Red light is focussed further away from the lens. This variance in focal length results in small degradations in image quality. This effect is more prominent when viewing certain objects such as planets. To eliminate this aberration a series of lenses are used to manipulate the light so that the focal lengths converge. By converging the focal lengths, quality can be improved. However, the extra material and expertise required to build these compound lenses increases the price of telescopes using this setup. **JB**

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Comets are made from leftover material that made up the planets

DEEP SPACE

How are comets made?

Jasmine Beck

It's said that comets are made from the leftover material, namely lumps of leftover space debris, that formed the planets and make up the Solar System we know today.

The Solar System was made by a huge diffuse object consisting of clouds of gas and dust, which collapsed some 4.6 billion years ago. Most of the cloud, which had flattened into a disc around a young Sun, clumped together to make the planets. However, some small lumps remained and became chunks of frozen gas and dust, living in the outer region of the Solar System where it's cold enough to make the frozen ices that give comets their tails. **GL**

Sunspots can get exceptionally large, reaching diameters many times larger than Earth

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SOLAR SYSTEM

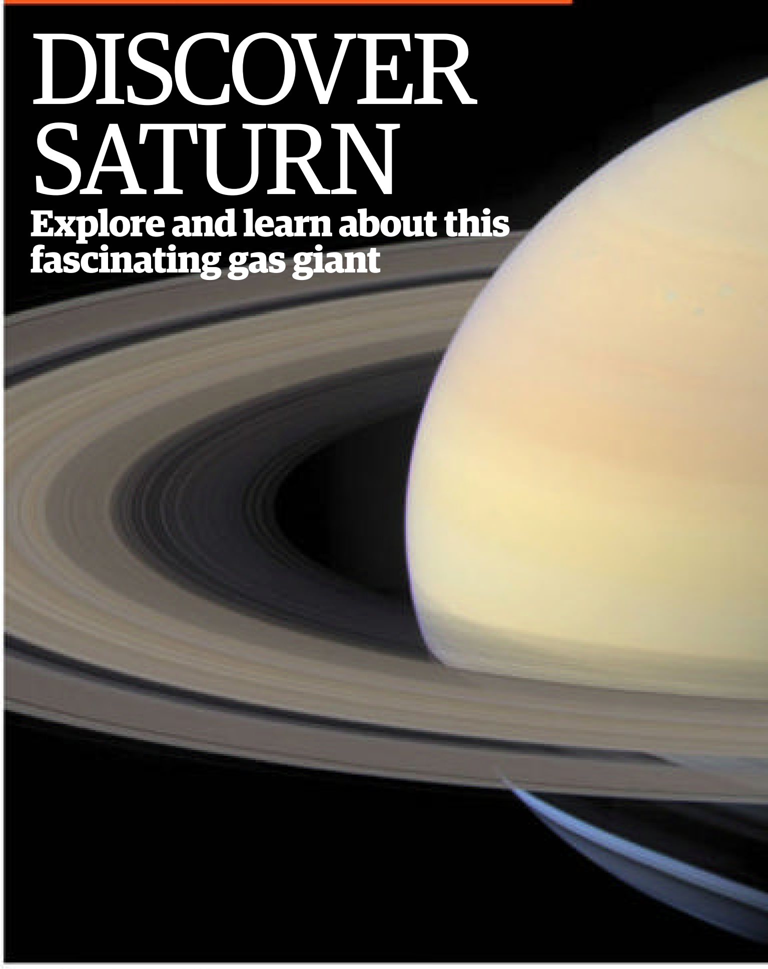
How big can sunspots get?

Alan Breen

In short, sunspots are characterised as dark, cooler regions where the Sun's internal magnetic fields rise up through its surface layers. They can get exceptionally large and reach sizes many times bigger than Earth. In fact, there have been many recorded instances of sunspots reaching huge proportions. One spotted in 2014, known as Active Region 12192, was the largest seen for 24 years. It covered a region about 4 billion square kilometres (1.65 billion square miles), almost the same size as Jupiter.

Sunspots are closely associated with solar flares and coronal mass ejections, which are eruptions of material thrown from the Sun's surface and out into space. **GL**

Next Issue

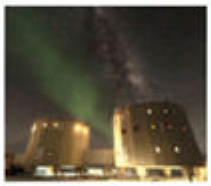


DISCOVER SATURN

Explore and learn about this fascinating gas giant

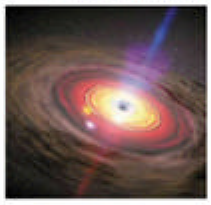
HOW TO BUILD A GALAXY

See how these massive, billion star systems are formed



ICE WORLD EXPLORATION

How to survive the extreme conditions on distant moons



20 SPACE MYTHS BUSTED

Why the Sun isn't burning, black holes don't suck, plus other misconceptions

In orbit
30 Apr
2015

SPACE HOTELS
SPRING GALAXY TOUR
SATURN OBSERVER'S GUIDE
WATCH BETELGEUSE EXPLODE
AMAZING FACTS ABOUT CERES
WHICH ARE THE BIGGEST CRATERS?

STARGAZER

GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

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Learn how to track exoplanets from home

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Our guide to spotting near-Earth objects

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Find the most spectacular night-time sights

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Readers showcase their best astrophotography images

92 **Astronomy kit reviews**
The latest essential astronomy gear and telescopes reviewed

A reflecting telescope with a minimum 8" aperture is required for exoplanet viewing

What do I need for exoplanet transit observing?

- ✓ Reflecting telescope with an 8" aperture or above
- ✓ CCD camera
- ✓ Computer or laptop
- ✓ BB filter
- ✓ List of known exoplanets
- ✓ List of all the predicted transit times
- ✓ Consistently clear and moonless night
- ✓ Photometry software
- ✓ Spreadsheet software
- ✓ Patience and perseverance

Jargon buster

Magnitude
A measure of how bright a star appears in the sky. There is a difference in brightness of 2.5-times between each magnitude.

CCD
Charge-coupled device. It is the imaging chip found in digital cameras. Specific CCDs are made for astronomy cameras.

Photometry
The measurement of intensity of radiation from an astronomical object. It comes from the Greek words for light and measure.

See an exoplanet today

All About Space shows you how to observe an alien world outside of the Solar System

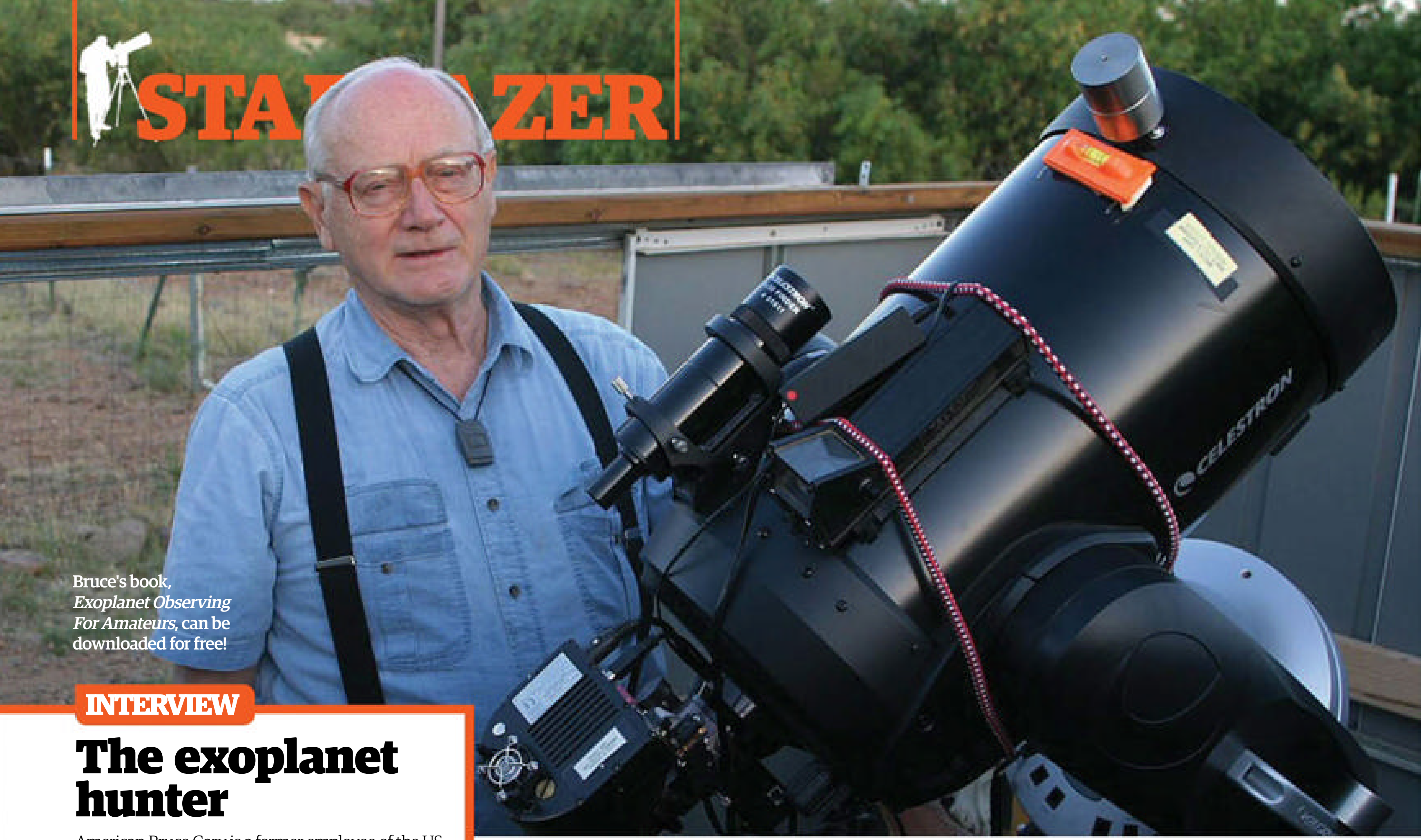
The discovery of planets orbiting around other stars has revolutionised modern astronomy. Around 2,000 have been spotted since the first, back in 1995. Famous professional observatories like the Kepler Space Telescope have uncovered seemingly Earth-like planets around Sun-like stars. Our understanding of our place in this vast universe is being sculpted day by day thanks to this seemingly endless stream of discoveries.

And yet, it is not just professional astronomers who can get in on the act, you can too. Amateur observing equipment has never been so advanced and inexpensive. These days, a determined amateur, armed with dogged perseverance and patience, can observe exoplanets too. You don't need a telescope in space or high up a mountain – one located in your back garden will do the trick.

You won't be able to see the planet itself, but you'll be able to see where it is using the transit method – the same hunting technique deployed by Kepler. If the alignment is right, every time an alien planet orbits its star, it will pass directly between the star and us. The presence of the planet will temporarily block out some of the star's light, causing it to dim slightly. These changes are minute – 0.01 per cent for an Earth-like planet passing in front of Sun-like star and one per cent for a Jupiter analogue. Such dimming is imperceptible to the human eye.

From these transits you can infer a lot of information about the planet. First off, you know how big it is as bigger planets block out more light. You can also tell how long it takes to orbit its star by seeing how often the transits occur. Rapidly-repeating transits mean the planet is whizzing round on a speedy orbit like Mercury. Much greater gaps between transits imply a more leisurely orbital pace. This also portrays how far the planet is from its star. Nearer planets have shorter orbits, more distant planets have longer orbits. In turn this will tell you something about the temperature on that planet, as the nearer it is to its star the hotter it will be. If the temperature turns out to be between 0 and 100 degrees Celsius (32 and 212 degrees Fahrenheit), liquid water might just exist there and the prospect of life enters the picture.

So what do you need to start picking up some of these subtle changes in a star's light? The first, most obvious answer is a telescope. Because these changes are so small, it means that you're going to need a lot of patience and the will to undertake several rounds of trial and error to get your setup working for you. The brightest stars with known transiting planets are around a tenth magnitude



Bruce's book, *Exoplanet Observing For Amateurs*, can be downloaded for free!

INTERVIEW

The exoplanet hunter

American Bruce Gary is a former employee of the US Naval Research Laboratory where he worked on radio astronomy and studied Jupiter. He then went on to work in aviation safety before switching to the study of the atmosphere and the hole in the ozone layer. Upon retiring he returned to his boyhood passion for observational astronomy and began hunting out exoplanets from his personal observatory in Hereford, Arizona. **All About Space** caught up with him to find out more about his passion.

How did you get into exoplanet observation?
After reading an article that claimed amateurs were capable of detecting the presence of a planet orbiting in front of a star, I exclaimed, "Wow, could I do that?" .

What is the most exciting exoplanet discovery you have made?
The most exciting thing that I've found is a distant solar system that is still forming, as a small star orbiting a bigger one in an orbit that changes on monthly timescales.

What advice would you give to anyone starting to look for exoplanets?
Take your time and figure things out slowly and methodically, because there are many gremlins waiting to trip you up; but please make sure you enjoy that process!

Can amateur observations make any real contribution toward our understanding of alien worlds?
Amateur observations of exoplanet transits are slowly losing value in terms of any real contribution that can be made, because professional astronomers are now constructing telescope systems that mimic a lot of what only amateurs were once equipped to do.

which is about 12.5-times dimmer than your eyes can see under the best viewing conditions. An eight-inch reflector is really the bare minimum - ideally you'd want ten inches or above. You're also going to need a CCD camera to take images of the star in question over many hours, as later you'll use computer software to make measurements of its brightness and plot how that changes over time. The right filter is also a must. You'll want a BB filter (BB stands for blue blocking). Companies like Astrodon make a dedicated exoplanet version of this filter.

Unlike taking pictures of planets or nebulae, dark skies are not an absolute requirement and they are not perfect seeing conditions either. 'Seeing' is a measure of the turbulence in the atmosphere which can distort images - it is why professional telescopes are positioned high up on mountains to get above the thickest part of the atmosphere and improve seeing.

If you're attempting an exoplanet observation for the first time, you're going to want to test out your equipment on known exoplanets. So, to kick off, you're going to need a list of bright transiting exoplanets or BTEs. You'll also need to know when the planet is set to transit in front of its star - it is no good observing the star when the planet is hidden behind it! For that you can try the Exoplanet Transit Database, which is maintained by the Czech Astronomical Society.

So you're happy with how your telescope, filter and CCD works and you've identified a suitable exoplanet. You're now looking for a clear night that coincides with a predicted transit. Weather is particularly crucial - transits take hours from start to finish and you'll need to be taking observations throughout. Broken observations due to intermittent cloud are no good. A moonless night is also a bonus.

If you're lucky enough to get these conditions, you can set your telescope up on your chosen star at the beginning of the evening. A key part of processing your observations is a reference star; another star in the same field of view as your main target. So be sure to position your main target in such a way that you can see at least one other star. Calibrate your CCD so that it is ready to start taking images and consult a guide on CCD observations if you're not sure about things like flat frames, dark frames and exposure times. You're then set to make your observations.

Once you have your images, it is time to start processing them. Your goal is to use the photometry tool in image-analysis software to obtain measurements of the brightness of your target star at regular intervals throughout your run. You can then put these measurements into a spreadsheet and plot a graph of brightness over time. With luck you should see the brightness drop before returning to its original level, that's your transit. Amateur exoplanet hunter Bruce Gary has an excellent book, available as a free PDF, which goes through all the required steps in more detail. You might also want to look at OSCAAR (Open Source differential photometry Code for Accelerating Amateur Research). It is a free piece of software that takes your raw images and turns them into a light curve.

It may sound like a daunting task, but seeing the effect a planet has on the light from its parent star will be worth the effort. If you really get into exoplanet observing, you might want to start contributing your data to the astronomical community. This can be done through the Exoplanet Transit Database. The citizen science project known as Planet Hunters, **www.planethunters.org**, asks volunteers to look through light curve transit data from the Kepler Space Telescope. Whether you are thinking about observing exoplanets for yourself, or contributing via citizen science, there has never been a better time to get involved in exoplanet research. ●

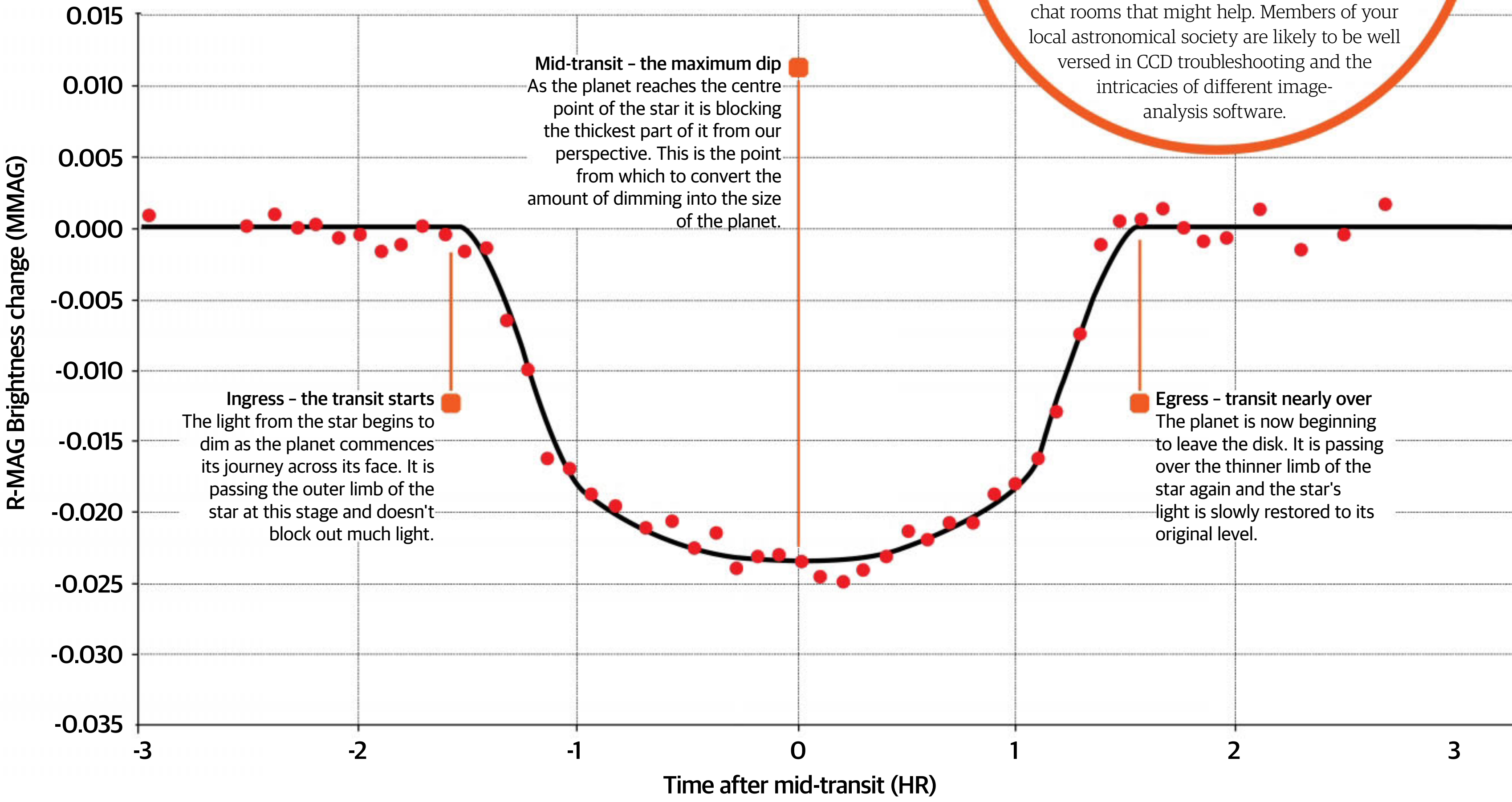
Understanding image-analysis software is key

What do I do if I'm unsure?

Exoplanet observing is tough, so getting advice is something you're likely to consider at some stage. As mentioned in the main text, Bruce Gary's free PDF guide is a great source of information. You may also want to consider joining the American Association of Variable Star Observers (AAVSO). Membership is open to all nationalities and they have online forums and live chat rooms that might help. Members of your local astronomical society are likely to be well versed in CCD troubleshooting and the intricacies of different image-analysis software.

What will I see?

Learn how to sort your new data just like the professionals with our guide to spotting transit patterns



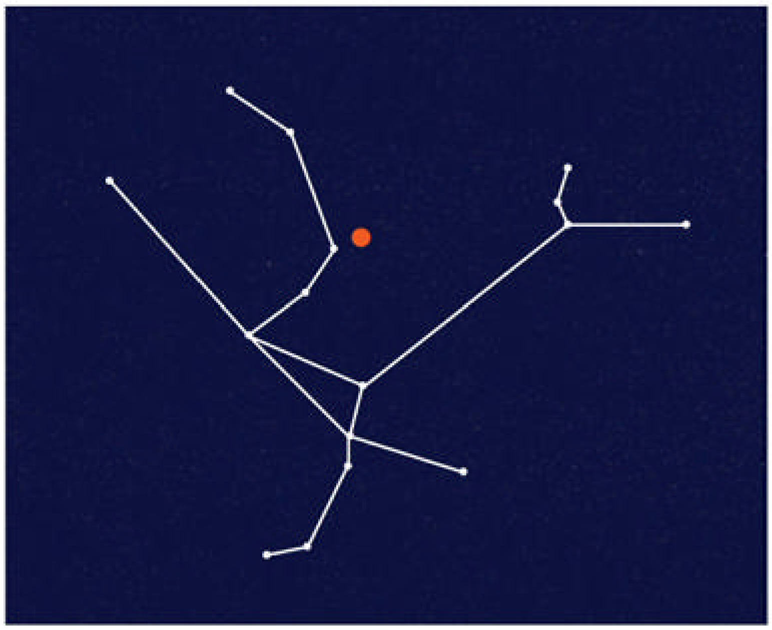
Mid-transit – the maximum dip
As the planet reaches the centre point of the star it is blocking the thickest part of it from our perspective. This is the point from which to convert the amount of dimming into the size of the planet.

Ingress – the transit starts
The light from the star begins to dim as the planet commences its journey across its face. It is passing the outer limb of the star at this stage and doesn't block out much light.

Egress – transit nearly over
The planet is now beginning to leave the disk. It is passing over the thinner limb of the star again and the star's light is slowly restored to its original level.

Top alien world targets

Here are four exoplanet targets to try your hand at observing - minimum 8" reflecting telescope required

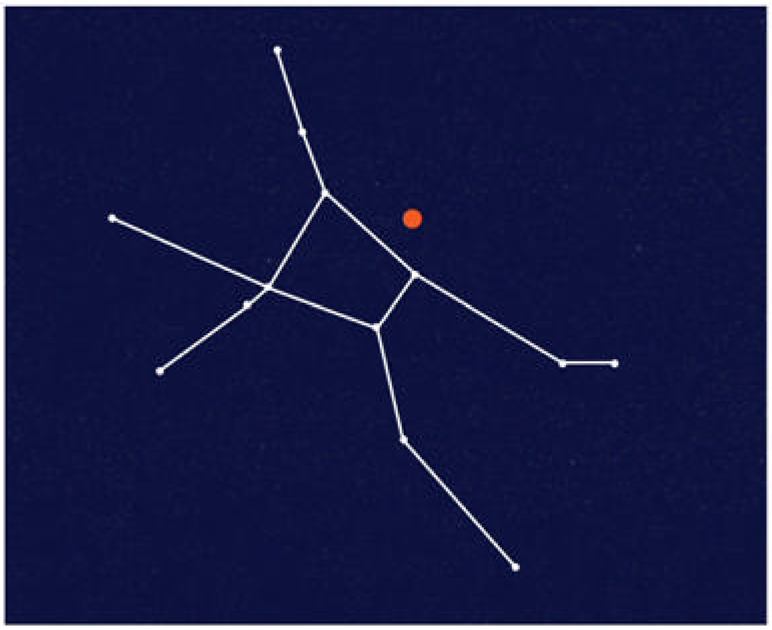


HD 15082 b

Constellation: **Andromeda** **Star:** **HD 15082 (also known as WASP-33)**

Observer's notes:

At magnitude 8.3, this star is one of the brightest and therefore most accessible when it comes to spotting its transiting exoplanet. The planet orbits every 1.2 days and the transits themselves only last around three hours. Andromeda is in the sky all year round, making it a great beginners target.

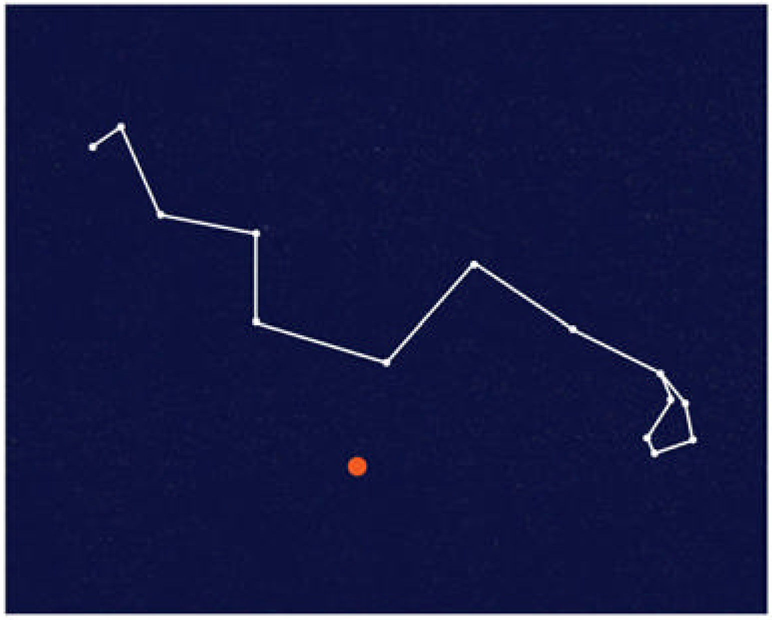


WASP-38b

Constellation: **Hercules** **Star:** **WASP-38**

Observer's notes:

Again, this star sits under a magnitude of ten, making it more accessible. However, the dip of the transit itself is not very deep and it might take a bit of teasing out. The planet's period is just under seven days and the transits last for just over 4.5 hours.

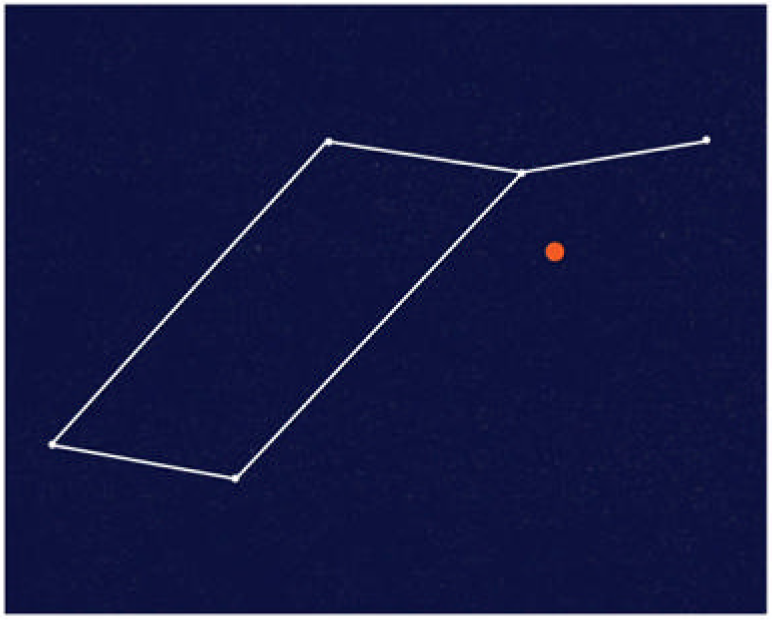


WASP-15b

Constellation: **Hydra** **Star:** **WASP-15**

Observer's notes:

Located 1,000 light years away, this star has a known exoplanet about half the mass of Jupiter. It completes its orbit in just 3.75 days and transits last for 3.5 hours. The star is larger, hotter and brighter than the Sun. From Earth, however, it appears with a magnitude of 10.9.



WASP-3b

Constellation: **Lyra** **Star:** **WASP-3**

Observer's notes:

Found in the constellation of Lyra, this transit is primed for viewing in the summer months. The planet has a mass twice that of Jupiter and completes an orbit in less than two days, with transits lasting just under three hours. It shines with a magnitude of 10.6.

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How to spot Near Earth Objects

All About Space tells you all you need to know about observing asteroids and other space objects

Our Solar System is littered with debris. Most of it left after the formation of the Sun and planets. It takes the form of rocks of all shapes and sizes. These include such objects as meteoroids, comets and other icy bodies.

All of these objects follow their own orbits around the Sun and some of these can come quite close, astronomically speaking, to Earth. These are called Near-Earth Objects, or NEOs and there are a lot of them out there. However, we don't know just how many. They vary in size from rocks a few metres in diameter, to asteroids many tens or even hundreds of metres across. There are some which can cross the orbit of the Earth around the Sun and these are known as Potentially Hazardous Objects or PHOs. Although the risk from these objects depends largely on their size, it is quite rare for any large objects to come close to us. However, the risk is not insignificant. There are three categories of near-Earth asteroids which are potentially hazardous; Amor asteroids approach the orbit of the Earth from outside, Apollos cross the Earth's orbit and finally Aten asteroids approach Earth's orbit from inside.

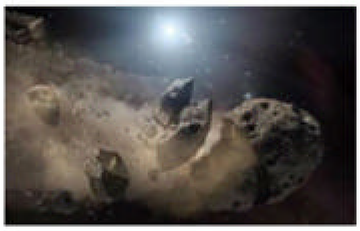
Is it possible to spot any of these objects using amateur equipment? The answer to this is yes, but it can be quite difficult because most of these objects are quite small and therefore faint. It would only be the larger NEOs that would be detectable by amateur astronomers. However, many amateurs are equipped with telescopes that have an aperture of ten inches or more, as well as sensitive cameras and so have more chance spotting such objects. There are, on occasion, objects which fly past us that are large enough to be picked up in small telescopes or even binoculars but these are quite rare events.

However there have been two or three such objects in the last few years and there certainly will be more in the future. The most recent (at the time of writing) was Asteroid 2004 BL86, which flew past the Earth on 26 January 2015. It came relatively close to us at a distance of 1,198,961 kilometres (745,000 miles), quite close for an object which is nearly 0.5 kilometres (0.3 miles) across! As its name suggests, it was first discovered in 2004 and was tracked continuously. It was expected to be bright enough to be seen in a three-inch aperture amateur telescope and at a magnitude of nine, or maybe even large binoculars. As it was, it was seen by many amateur astronomers and imaged by many more. It was quite fast moving, so charts and co-ordinates were a necessity for finding and tracking this object as it sailed past our planet. It will be the closest this particular object will come to us for the next 200 years at least.

In 2004 an asteroid named Apophis was discovered and the initial calculations suggested that it had a 2.7 per cent chance of impacting the Earth in 2029. It is a piece of rock some 370 metres (1,214 feet) across, which could do significant damage should it hit the Earth's surface. However, subsequent refining of the calculations showed that this will not occur, although it will come very close to us. It will also become bright, but so little that it will probably only be visible in professional telescopes. Earth's gravitational tug will change Apophis's orbit from that of an Aten class object to that of an Apollo class object. It will return, but any further approaches it makes to Earth will be more distant than in 2029.

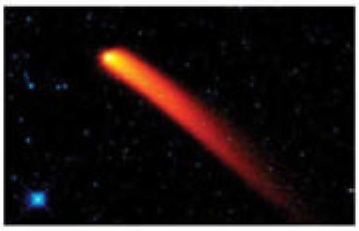
To date there are around 12,000 known and catalogued NEOs out of a potential 100,000 or more such objects. Due to the size and faintness of these objects it can be difficult for the casual backyard astronomer to find known NEOs, let alone discover new ones, but it is not impossible. Serious amateurs are joining in the hunt for NEOs using larger instruments and sensitive CCD cameras. If you don't possess such instruments, it is possible to use remote-controlled telescopes via the Internet and there are now several such telescopes and networks of telescopes available for public use, although there is usually a fee charged to help pay for the maintenance and upgrade of the equipment.

Types of NEO



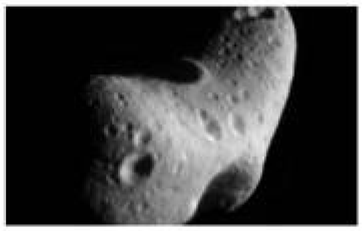
Meteoriod

A small asteroid with a diameter of 10m (32.8ft) or less. It's usually a fragment of a larger asteroid.



Comet

These icy rocks rarely approch within 1.3AU of the Sun but when they do, they're considered to be a NEO.



Asteroid

Any natural rocky or metallic body greater than 10m in diameter. The 16km (10mi) Eros is a massive NEO.

Man-made object

Sometimes boosters and other non-natural objects are lost in space, only to end up in a similar orbit to Earth.

How to spot Near Earth Objects

So far, professional and amateur astronomers have together discovered over 12,000 NEOs

What is a NEO?

Near-Earth Objects (NEOs) are objects such as meteoroids and asteroids, which orbit very close to the Earth. Meteoroids can be anything from the size of a grain of sand to rocks up to ten metres (32.8 feet) across. Asteroid is the term used for stony or metallic objects which range from ten metres (32.8 feet) to many hundreds of metres in diameter. The term can also include man-made satellites and all NEOs have a closest approach to the Sun of less than 1.3AU. An Astronomical Unit (AU) is the average distance from Earth to the Sun, which is 150 million kilometres (93 million miles).

There is a large online community of commited NEO hunters

Getting involved

You can get involved in hunting for Near-Earth Objects through your local astronomical society, or through organisations such as the British Astronomical Association (BAA), or agengies like ESA or NASA. If you possess a large telescope and CCD camera you can check out the International Astronomical Union (IAU) Minor Planet Center's website (www.minorplanetcenter.net) for objects which need follow-up observations. Take a look at Peter Birtwhistle's website (www.birtwhistle.org) which is packed with information for would-be amateur NEO hunters. The Internet is a great source of knowledge about such objects and how to start tracking them down.

It is also wise to join a programme where you work alongside teams of avid asteroid hunters. This helps to give your research focus and prevents you re-discovering already-known objects. There are bodies co-ordinating such searches, including NASA and the ESA .

How are NEOs discovered? Images are taken at regular intervals, often between 15 and 30 minutes, of the same area of the sky and the pictures are blinked to see if any of the stars have changed position from one image to the next. If so, it is almost certainly a Solar System object, as the background stars do not move appreciably even over much larger periods of time. The moving object then has to be assessed and compared to any known objects once its orbit has been figured out, only then can it be decided if the object is already known or if it is in fact a discovery. It can be quite exciting to find that an object you have recorded is new to science! All reports of such discoveries, if they are confirmed, are co-ordinated by the International Astronomical Union's Minor Planet Center in Cambridge, Massachusetts, USA. They have a huge database recording all the known asteroids and minor planets in the Solar System, so it is relatively straightforward to check new discoveries against the orbits of thousands of previously-known objects. So far nearly 300 new NEOs have been discovered between January and March this year alone, mostly by automatic sky surveys, but amateurs are becoming increasingly important to the work of discovering and tracking these elusive NEOs.

There are just so many objects out there which need discovering and tracking, that it is an almost impossible task for the professionals to carry out alone, so amateur NEO hunting provides a valuable contribution to our knowledge of where, what and how large these objects are and helps to define how much of a threat, if any, these things are to us. If you reside in the UK, a good place to start is the British Astronomical Association's Asteroids and Remote Planets Section, as they help co-ordinate observations by amateur astronomers interested in discovering Near-Earth Objects. There is also the Near-Earth Object Program run by NASA. Follow-up observations are also important after discovery of a NEO, which can be difficult for the professionals to carry out due to a lack of resources. Some astronomy clubs carry out observations, detections and follow ups of such objects and also prove a useful place to channel your interest, as you would be working with like-minded people. Scientific bodies such as NASA and ESA are turning to crowd sourcing to help the hunt for NEOs. This includes putting out images taken by large professional telescopes and getting enthusiastic amateurs to search them for tell-tale tracks of potential unknown objects in the night sky.

This is a fairly new and interesting field for amateur astronomers to get involved with and a very exciting chance to carry out meaningful observations and scientific research that will help scientists for many years to come.

"An asteroid named Apophis had a 2.7 per cent chance of impacting the Earth in 2029"

© Alamy; NASA

What's in the sky?

Spring skies reveal the Realm Of The Galaxies as we look out beyond our own Milky Way

Using the sky chart

Please note that this chart is for midnight mid-month and set for 45° latitude north or south respectively.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

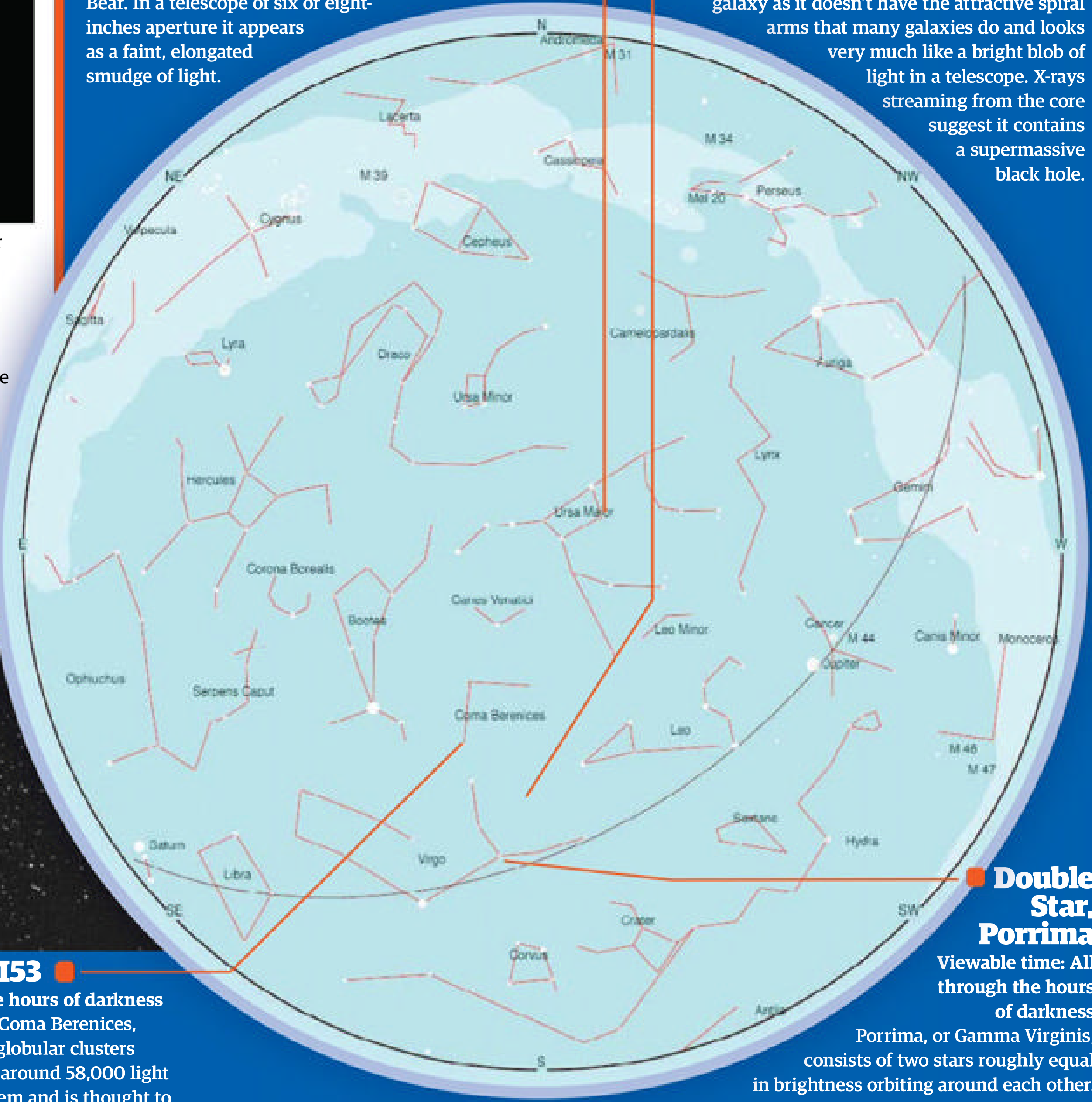
03 The constellations on the chart should now match what you see in the sky.

Galaxy, M108

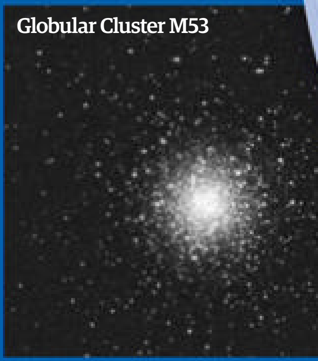
Viewable time: All night long
Also known as the Surfboard Galaxy, M108 is a barred spiral galaxy with loosely wound arms. It appears to lie quite close to the star Merak or beta Ursa Major in the constellation of the Great Bear. In a telescope of six or eight-inches aperture it appears as a faint, elongated smudge of light.

Galaxy, M49

Viewable time: All through the hours of darkness
Nestling in the bowl of the constellation of Virgo, this is an unusual galaxy as it looks as though it should be a radio galaxy, which is a source of strong radio signals, but it's not. It's an elliptical galaxy as it doesn't have the attractive spiral arms that many galaxies do and looks very much like a bright blob of light in a telescope. X-rays streaming from the core suggest it contains a supermassive black hole.



Northern hemisphere



Globular cluster, M53

Viewable time: All through the hours of darkness
Located in the constellation of Coma Berenices, this is one of the more remote globular clusters associated with our galaxy. It's around 58,000 light years away from our Solar System and is thought to be over 12 billion years old, containing around half a million stars. It shows up in binoculars as a small misty patch of light. A small telescope will reveal its nature and resolve the outer stars in the cluster.

Double Star, Porrima

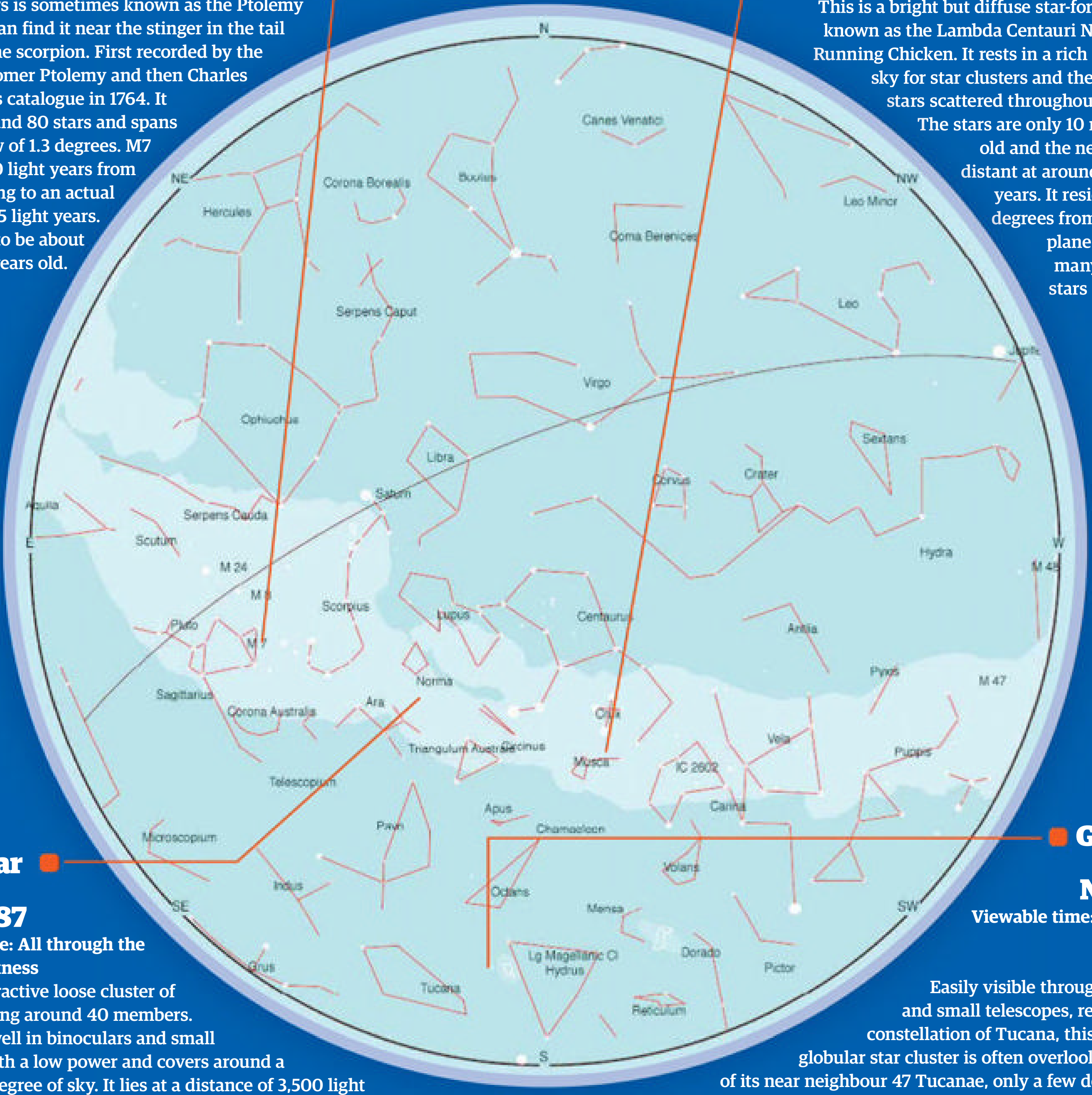
Viewable time: All through the hours of darkness
Porrima, or Gamma Virginis, consists of two stars roughly equal in brightness orbiting around each other. It has an orbital period of 168.93 years and the distance between the two stars seems to vary over this time. It was easy to separate these two objects in amateur telescopes up until the 1990s.

Open star cluster, M7

Viewable time: Late evening until dawn

Easy to spot with the naked eye, this lovely open cluster of stars is sometimes known as the Ptolemy cluster. You can find it near the stinger in the tail of Scorpius the scorpion. First recorded by the Greek astronomer Ptolemy and then Charles Messier in his catalogue in 1764. It contains around 80 stars and spans a field of view of 1.3 degrees. M7 is around 980 light years from Earth, equating to an actual diameter of 25 light years. It is thought to be about 200 million years old.

Southern hemisphere



IC 2944, The Running Chicken Nebula

Viewable time: All through the hours of darkness

This is a bright but diffuse star-forming nebula known as the Lambda Centauri Nebula or The Running Chicken. It rests in a rich region of the sky for star clusters and there are young stars scattered throughout the nebula. The stars are only 10 million years old and the nebula is fairly distant at around 6,000 light years. It resides only two degrees from the galactic plane, so there are many foreground stars to be seen in this region.

Open star cluster, NGC 6087

Viewable time: All through the hours of darkness

This is an attractive loose cluster of stars containing around 40 members. It shows up well in binoculars and small telescopes with a low power and covers around a quarter of a degree of sky. It lies at a distance of 3,500 light years. This can be determined with some accuracy as the cluster contains a Cepheid variable star, a type used as a standard candle for distance measurements in deep space.

Globular cluster, NGC 362

Viewable time: All through the hours of darkness

Easily visible through binoculars and small telescopes, residing in the constellation of Tucana, this fairly bright globular star cluster is often overlooked in favour of its near neighbour 47 Tucanae, only a few degrees to the east. However, it is still a very attractive object for study. It was discovered in August 1826 by James Dunlop and is thought to be over 10 billion years old.

Open star cluster, NGC 6087

IC 2944, The Running Chicken Nebula

© NASA/ESO; NASA/ESA/Hubble Space Telescope

Me & My Telescope

Send your astronomy photos and pictures of you with your telescope to **photos@spaceanswers.com** and we'll showcase them every issue

The Moon

Alastair Leith

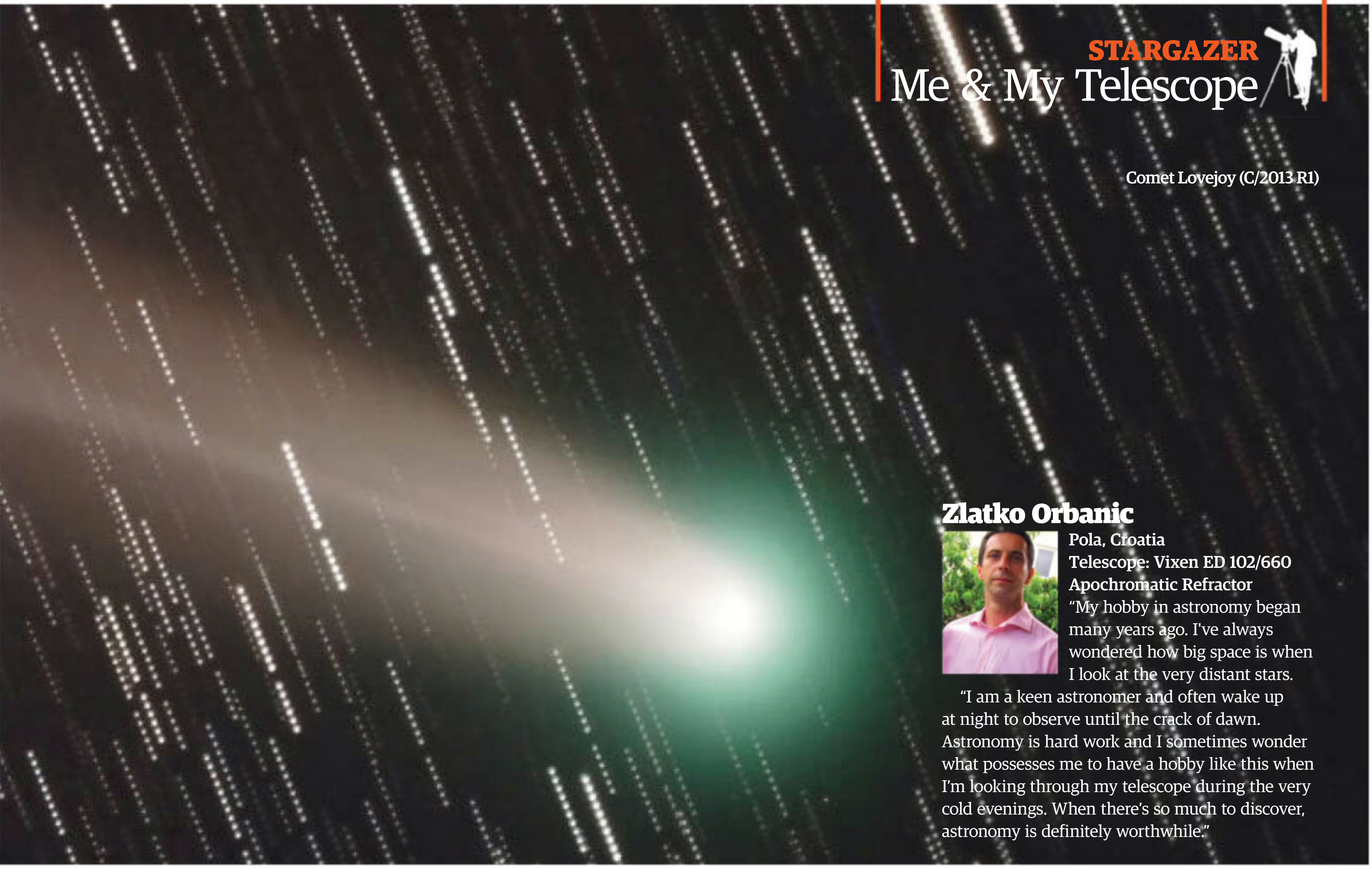
Northampton, UK

"I have been interested in astronomy since I was a young boy growing up in East London with Halley's Comet in the skies. Over the past year my interest has received a new injection of passion and enthusiasm with a new mount, which is computer-driven and allows me to take images like these.

"I also enjoy spectroscopy, so once I have finished observing and imaging I focus my attention on that. If it's a moonless night, I turn my attention to any galaxies that are in the sky at the time."

The Moon and Venus

Partial solar eclipse



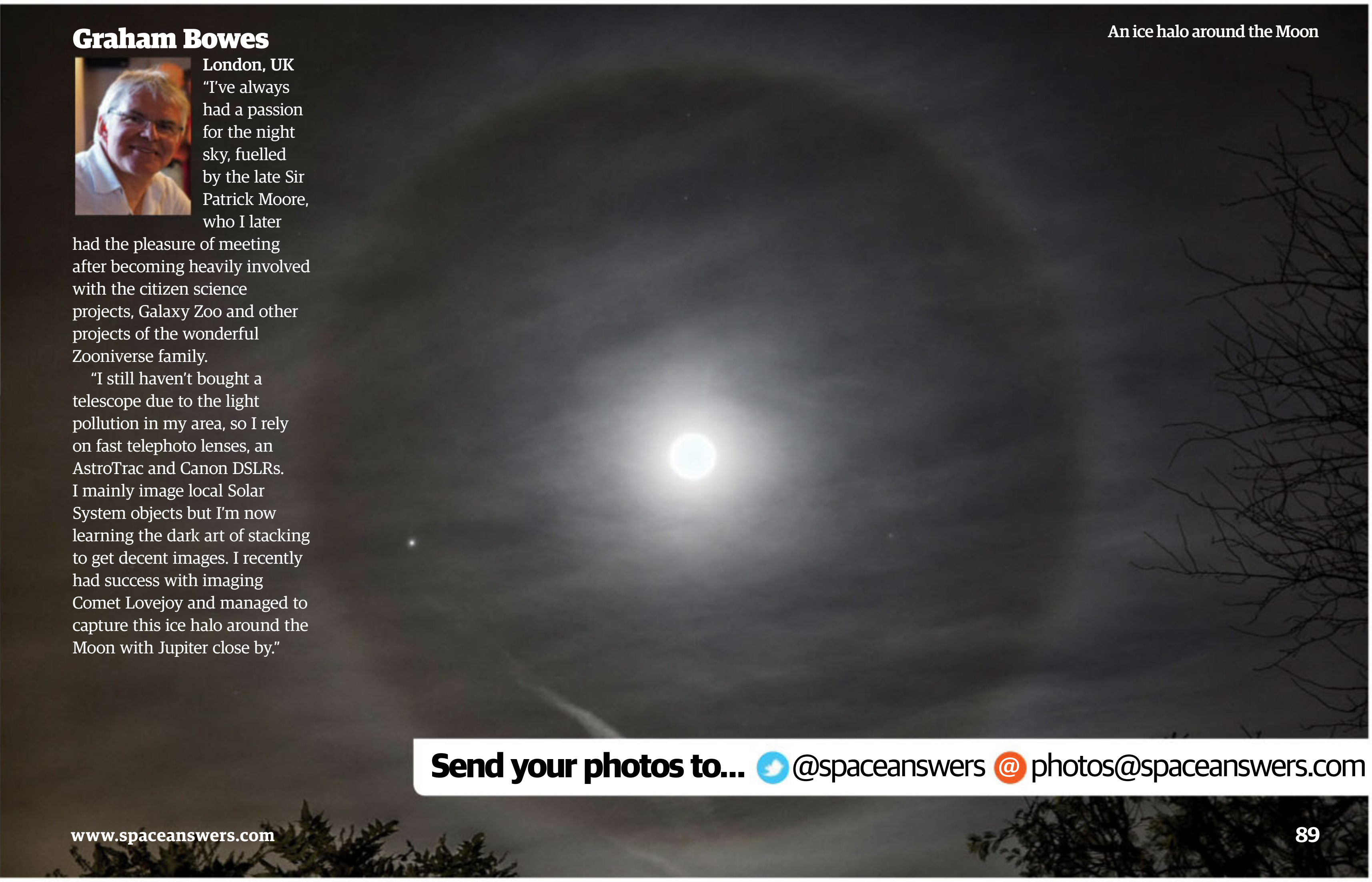
Comet Lovejoy (C/2013 R1)

Zlatko Orbanic

Pola, Croatia
Telescope: Vixen ED 102/660 Apochromatic Refractor

"My hobby in astronomy began many years ago. I've always wondered how big space is when I look at the very distant stars.

"I am a keen astronomer and often wake up at night to observe until the crack of dawn. Astronomy is hard work and I sometimes wonder what possesses me to have a hobby like this when I'm looking through my telescope during the very cold evenings. When there's so much to discover, astronomy is definitely worthwhile."



An ice halo around the Moon

Graham Bowes

London, UK

"I've always had a passion for the night sky, fuelled by the late Sir Patrick Moore, who I later had the pleasure of meeting after becoming heavily involved with the citizen science projects, Galaxy Zoo and other projects of the wonderful Zooniverse family.

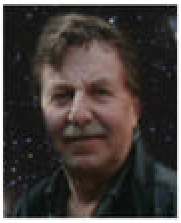
"I still haven't bought a telescope due to the light pollution in my area, so I rely on fast telephoto lenses, an AstroTrac and Canon DSLRs. I mainly image local Solar System objects but I'm now learning the dark art of stacking to get decent images. I recently had success with imaging Comet Lovejoy and managed to capture this ice halo around the Moon with Jupiter close by."

Send your photos to... @spaceanswers @ photos@spaceanswers.com

Stargazing stories

Email the story of how you got into astronomy to **photos@spaceanswers.com** for a chance to feature in **All About Space**

Terry Hancock



Location: Michigan, USA
Twitter: @turbo399
Info: Astronomer for 47 years
Current rig
Telescope: 12" Ritchey-Chrétien reflector and Takahashi E180 Astrograph
Mount: Paramount robotic equatorial mount
Other: QHY11S and QHY23 Monochrome CCD cameras

"Inspired by the late Sir Patrick Moore, my interest in astronomy, along with photography, began some 40 years ago in Australia. My first telescope was a 4.5" Newtonian reflector attached to a very crudely made German equatorial mount and my interest in astrophotography began in the early 1980s. Many nights were enjoyed observing the pollution-free night skies of the southern Australian outback, where it was so dark that the Milky Way cast a shadow.

"It wasn't until I moved to America and began using digital cameras that I took astrophotography very seriously, starting with a Canon DSLR, I progressed to a One-Shot Color CCD and later to Monochrome CCD cameras.

"All of my images are captured from my home in Michigan where the skies are mediocre. I use modest equipment, which is permanently mounted in a wooden 2.4 by 2.4-metre (8 by 8-foot) observatory and controlled remotely from inside my house. I pride myself on taking really long exposures of deep-sky objects to maintain a natural look.

"A good friend once said that I am 'the only guy he knows that has more money invested in his astronomy equipment than his house'!" ●

> "I pride myself on taking really long exposures of deep-sky objects"

Terry's top three tips

1. Choose your telescope carefully

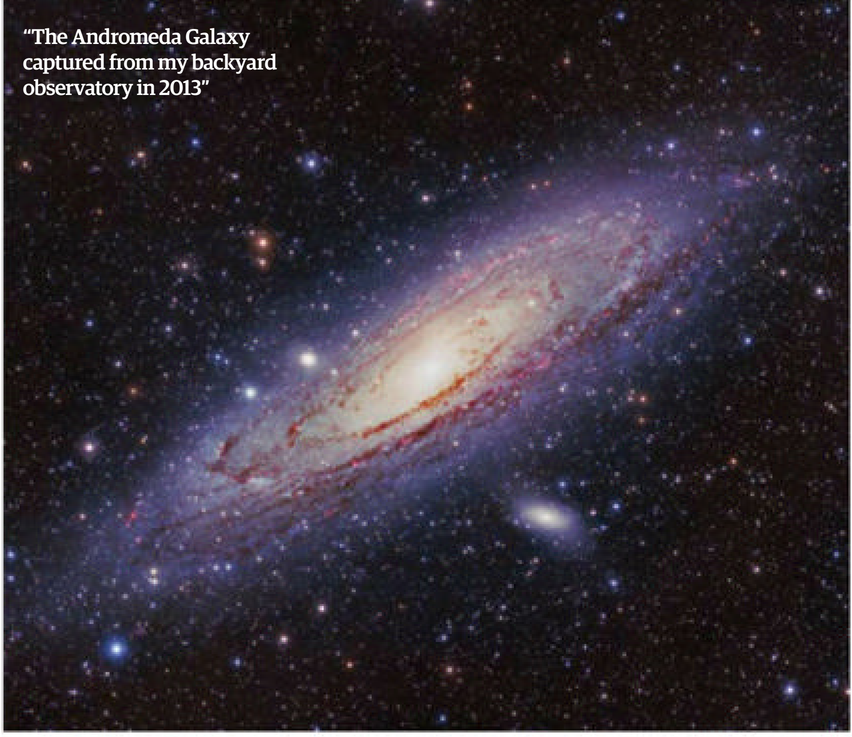
When selecting your very first telescope I recommend a 2" to 5" apochromatic refractor with a focal length of no more than 900mm.

2. Try using a motorised mount

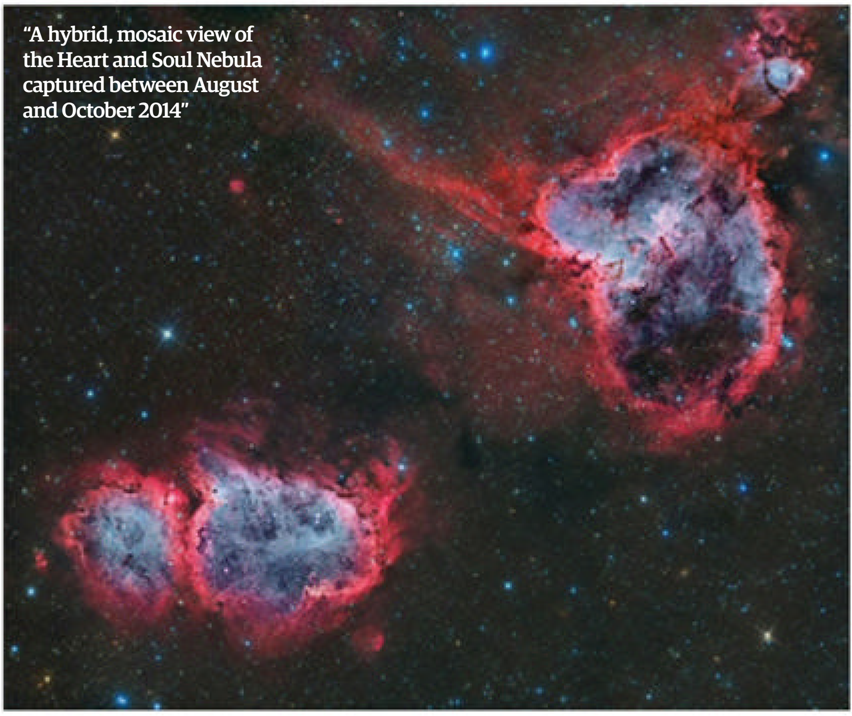
The all-important telescope mount should be a motorised equatorial type with a hand control that is capable of supporting a telescope.

3. Start out simply

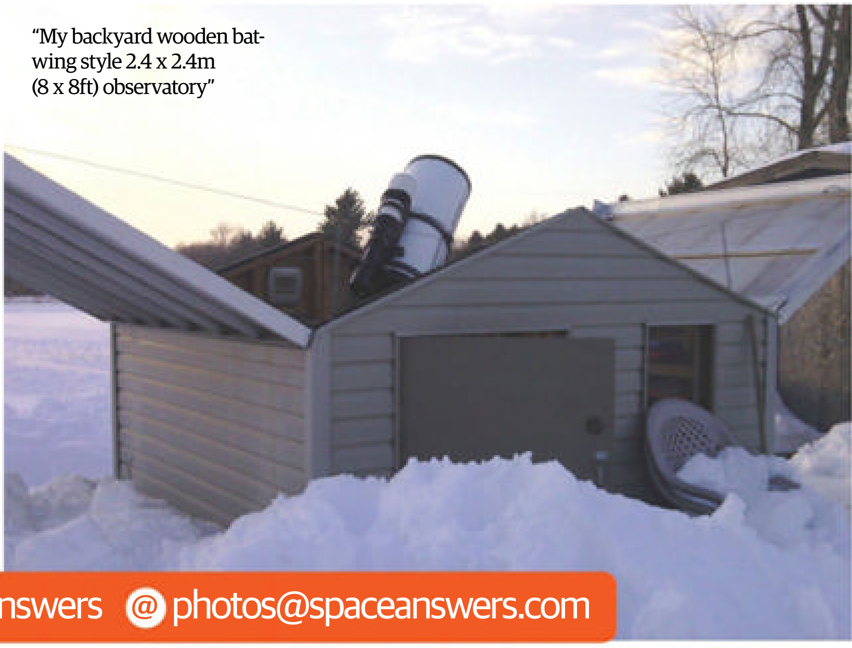
Astrophotography is a steep learning curve, so start with a DSLR. Should you decide to purchase a CCD camera at a later date, I suggest a One-Shot Colour CCD.



"The Andromeda Galaxy captured from my backyard observatory in 2013"



"A hybrid, mosaic view of the Heart and Soul Nebula captured between August and October 2014"



"My backyard wooden bat-wing style 2.4 x 2.4m (8 x 8ft) observatory"

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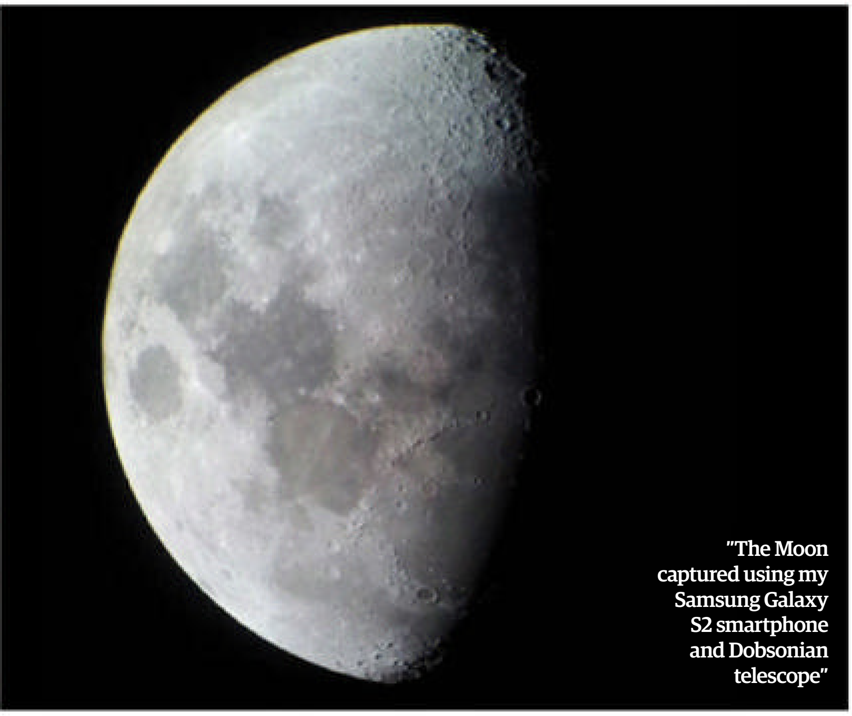
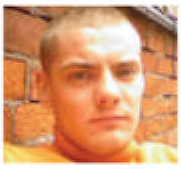
"Star trails with Polaris, the North Star at the centre"



"The Moon captured using my Samsung Galaxy S2 smartphone and Dobsonian telescope"

"An Iridium flare taken with my Canon 600D"

Dainius Saulys



Location: Northampton, UK
Info: Astronomer for three years
Current rig
Telescope: Orion SkyQuest XT8 Dobsonian
Mount: Alt-azimuth
Other: Orion Scenix 10x50 binoculars, Canon 600D

"My interest in the night sky began when I saw Comet Hale-Bopp during 1997, when it was visible to the naked eye for an incredible 18 months.

"After seeing the comet, I borrowed a telescope from my high school and observed the Moon's lunar mare and craters closely. I found it to be an incredible experience as I toured the night sky.

"It wasn't long before I graduated from high school and became embroiled in day-to-day life, but despite this I never forgot the night sky. A good 15 years later, I bought my first ever astronomy book, which then led me to buy a pair of 10x50 binoculars to observe the night sky. I used my binoculars for a long time before I finally convinced myself to buy my first telescope.

"The moment I put my eye to the eyepiece, that was it. I became hooked on astronomy immediately and within two years I managed to observe all of the Messier objects, galaxies, star clusters and nebulae in the northern hemisphere, catalogued by astronomer Charles Messier in 1771 and then [updated] later in 1967.

"I would very much like to observe the Southern Pinwheel Galaxy, also known Messier 83, but my biggest dream is to head over to a place like Australia or elsewhere in the southern hemisphere and see all of the treasures that we are able to observe in the southern night skies." ●

> "After seeing the comet, I borrowed a telescope from my high school"

Dainius's top three tips

1. Start off simple

Buy binoculars and a sky atlas if you have just started. If you are unsure if astronomy is for you, binoculars are cheap and don't need setting up like a telescope does.

2. Do your research

If you decide that astronomy is for you, then make sure you have done as much research as possible before you buy your first telescope as they are not cheap.

3. Get to know your telescope

Learn how to use your telescope during the daytime and ensure that you purchase a guide that advises what targets to observe.

Celestron Omni XLT 120

A quality telescope that is easily accessorised, the XLT 120 is ideal for observing the Solar System and some bright deep sky objects

Telescope advice

Cost: £525 ($649.95)
From: David Hinds Ltd
Type: Refractor
Aperture: 4.72"
Focal length: 39"

Best for...

- Beginners
- Medium budgets
- Planetary viewing
- Lunar viewing
- Bright deep sky objects
- Basic astrophotography

For the price, the XLT 120 is of exceptional quality, especially if you are a keen observer of Solar System targets such as the planets and our Moon. Since you don't need tools to set up the telescope, it takes a mere five to ten minutes to put this simple refractor together.

The XLT 120 is a fine example of a small to medium-sized refractor and this became evident when we turned it to a selection of objects in a relatively clear March night sky. We took advantage of a full Moon with the Celestron Omni and popped on the supplied 25mm eyepiece, which provides a magnification of 40x, into the 1.25" star diagonal and we were soon studying the lunar surface. The telescope's lenses are of superb quality, manufactured with StarBright XLT coatings to ensure bright and crystal clear views as we toured craters and mares as well as lunar rilles and mountains. Bright crater Aristarchus was a stunning sight, as were the craters Kepler, Copernicus and Tycho, whose rays, made when material was thrown up during their progenitor impacts, could easily be detected by the refractor. As we slewed across the Moon's surface, we noted the ease with which the German equatorial mount allowed the telescope tube to move. The mount's well-made stainless steel tubular tripod legs are exquisite, providing excellent support to the telescope and a good, solid base when combined with the counterbalance for anyone wishing to try their hand at basic astrophotography.

Sadly, we did notice a degree of colour fringing, or chromatic aberration, which gave bright objects a purple to blue colouring. For the cost of the telescope, we did expect this common flaw with refractor telescopes to be prevalent in the XLT 120, but we were delighted to see that our views of the night sky were not affected at all. In fact, the chromatic aberration is so small that we quickly forgot about this slight problem in the telescope's optical system.

The XLT 120 unfortunately doesn't come with a great deal of accessories apart from the aforementioned diagonal and 25mm eyepiece. But, being versatile and having a useful maximum magnification of over 280x, the refractor will serve as a good instrument for years to come, ensuring that the observer, particularly a beginner, doesn't outgrow it. The multi-coated 25mm eyepiece has very good eye relief and we were delighted to see that as with all Celestron eyepieces, it is of an excellent quality and build.

Putting the 6x30 finderscope to the test, we noted the clear and sharp views when we used it to guide us to the very bright star Sirius, which shines at magnitude -1.46. We noted that views were sharp across a good

A heavy duty German equatorial mount enables the telescope to be slewed smoothly and, combined with its sturdy tripod, allows a solid platform for both observing and astrophotography

We were impressed with the clear views supplied by the 6x30 finderscope

The Celestron Omni's tube is of impressive build and the refractor's optical system provides clear and sharp views of a variety of night sky objects with only a degree of colour fringing

> "The XLT 120 is a fine example of a small to medium-sized refractor"

proportion of the field of view with only slight trailing off at the edges of the field. We were quick to move over to gas giant Jupiter and its four largest moons: Ganymede, Io, Callisto and Europa and were impressed with the view overall, as the gas giant's disc popped into view and the satellites appeared as points of light. We did note a halo around the planet, which unfortunately didn't disappear until we popped in a filter. With Venus being in the sky we took the opportunity to observe it, as with views of many bright objects, there was purple colour fringing around the planet's bland disk. Red giant star Betelgeuse kept its stunning orange-red colour at 40x, while not too far away the Orion Nebula's diffuse gas and the Trapezium star cluster were picked up easily with the additional help of averted vision.

We can highly recommend the XLT 120. You don't get a great deal in the way of accessories, but you do get a decent optical system housed by a very well-built telescope tube that is combined with a sturdy mount. It might take some getting used to for novices, but it promises to last for many observing sessions. ■

One multi-coated 25mm eyepiece is included with the telescope to provide a magnification of 40x

Free stargazing apps

Looking for a stargazing companion that's free and easy to use? We put two of the best astronomy apps to the test

Star Tracker Lite

Cost: Free
From: iTunes

This was easy to download to a device that runs iOS and we were amazed by the smooth operation and excellent graphics of Star Tracker Lite. Unfortunately, this app is a 'try before you buy' version, only really providing you with a limited selection of features, but nevertheless, you can still use it to locate targets in the night sky. The full version of this app will cost you a modest £2.29 ($2.99).

If you just want to find a night sky target with minimum fuss, while being treated to beautiful graphics, then Star Tracker Lite is the app for you, since it only needs you to point your device at the sky to allow you to find an object. GPS is also integrated into the app, which automatically detects your location. You can even take a look at what the night sky looked like in the past and how it will look in the future.

One niggle is that the size and colour of several objects is a touch misleading for beginners to astronomy. For example, The Ring Nebula (M57) in the constellation Lyra won't appear as large or as colourful in the sky even with a telescope. Overall, Star Tracker Lite is a good app for those wanting to try this particular piece of software before they purchase the full version, or those that want something simple.

Night Sky Lite

Cost: Free
From: iTunes and Google Play

Night Sky Lite is available to anyone with a device that runs iOS or Android and allows you to identify everything in the night sky. The graphics are a good representation of what you might see in the sky at any time of the year and are easy to understand and use while remaining accurate. Downloading Night Sky Lite is simple but we did get two crash reports after closing the app down. You have to fix your location using a spinning globe too, which some users may find fiddly.

The app is easier to read on a larger screen such as an iPad and a phone screen is perhaps too small. We enjoyed the community feature, which suggests stargazing locations across the world, perfect if you like to travel to areas that have the darkest of skies, or even if you are looking for somewhere to observe in your area. A weather forecast is an excellent feature of the app, ensuring you're only staying up late for the absolute best observing conditions.

Verdict

Winner: Night Sky Lite

While Star Tracker Lite is a good, visually stunning app, we thought that Night Sky Lite is a much more accurate representation of what you should expect to see in the night sky. With a community feature that suggests the best stargazing sights and an inbuilt weather forecast, we think that astronomers will get much more use out of this app. Night Sky Lite is also available on a variety of platforms, while Star Tracker Lite limits itself to iOS.

All About Space EDITOR'S CHOICE

Astronomy kit reviews

Stargazing gear, accessories, games and books for astronomers and space fans alike

1 Eyepieces
Vixen LVW series

Cost: £185 / $269 each
From: Opticron

The build of these eyepieces is superb and of very high quality, due to their weight, eye relief and generally strong construction. The downside is that the Vixen LVW series is quite bulky.

At £185 ($269) each, these eyepieces may be considered incredibly expensive for most people's budgets but, when we put them to the test we could see why many astronomers would want eyepieces of the Vixen LVW series standard. When we plugged in our in-house 4.5" reflector, even the lowest power provided much sharper views and we were able to pick out finer detail on the Moon's surface. What's more, the eye relief is very generous, providing comfort and the colour contrast is truly excellent.

There is no question that the Vixen LVW series eyepieces are of excellent quality, but we did feel that there are cheaper alternatives out there, capable of doing a similar, if not the same, high quality job. ■

2 Binoculars
Vixen SG 2.1x42

Cost: £229 / $299
From: Opticron

Despite their general appearance, the Vixen SG 2.1x42 certainly pack a punch in design and performance. Shining a bright light into the lenses, the SG coating is backed up by the usual high quality of Vixen optics and the minimal housing is also of a very good standard, but does mean that there isn't much grip. The SG 2.1x42 does come with a thin neck strap to ensure that there are no accidents.

What we loved about these binoculars is that each barrel has its own focuser, but it does take a touch of getting used to. Pointing the binoculars toward the Moon, around 50 per cent of the field of view is sharp but anywhere beyond that and the image is distorted. The eye relief isn't brilliant with this design, so anyone with glasses may struggle. Waiting for a moonless night, we took the Vixens out for a second test. We are glad that we did as our view of the Milky Way was excellent. ■

3 Stereoscope viewer
OWL stereoscope with astronomical cards (Astro Set 2)

Cost: £35 (approx $52)
From: London Stereoscopic Company

It's a simple concept, but the OWL stereoscope combined with astronomical cards makes for an excellent gift for any space fan.

Using the Astro Set 2, which includes 12 astronomical stereo cards created by Brian May and depicts objects such as the Moon, Mars's surface and Comet ISON, we were able to combine the stereoscope viewer to get three-dimensional views of a variety of astronomical objects. The images on the cards are beautifully detailed, providing a life-like feel to alien landscapes and planets.

Unfortunately the stereoscope doesn't come with the astronomical cards but the device is discounted when purchased together. London Stereoscopic Company also supply another pack of astronomical cards, allowing you to get three dimensional views of many Solar System objects. ■

4 Game
Universe Sandbox 2

Cost: Approx. £17 ($24.99)
From: www.universesandbox.com

What would happen if the Moon exploded? Or if the Sun was replaced with a black hole? Or if Andromeda and the Milky Way collided and the planets of the Solar System were completely reversed?

Developer Giant Army's *Universe Sandbox 2* goes a step further to satisfy your need for cool space scenarios by giving you an entire universe in which you can create and destroy at will. It employs a sophisticated physics engine that builds on Giant Army's first simulator by including planet climate simulation, terraforming and planet-smashing impacts. It can really be as complicated or as crazy as you like, so if you want to simulate the effect of dark matter in the Milky Way or how light warps around Sagittarius A*, you can. It's accessible, educational and best of all, fun. *Universe Sandbox 2* is perfect for space enthusiasts and video gamers alike. ■

WIN

WIN A TELESCOPE BUNDLE WORTH OVER £1000!

We've got everything you need to get started in astronomy with our latest competition

Buzz Aldrin's Space Program Manager

From: slitherine.com

Cost: From £20.99 / $29.99

Straddling between an accessible management sim and informational game, *Buzz Aldrin's Space Program Manager* is a simple simulation that sees you take charge of a Fifties space agency, training, upgrading, and launching new missions. Ideal for casual gamers. (Tablet device not included.)

Ostara Flat Field eyepieces

From: Optical Hardware Ltd

Cost: £99.99 (approx. $154) each

View a selection of night-sky gems using these Flat Field 1.25" eyepieces (8mm, 12mm, 19mm and 27mm). Made to a high standard and providing superb views, this range from Ostara is suitable for a wide variety of telescopes and will provide you with more pleasing images of planetary targets and deep-sky objects than standard Plössl eyepieces.

Ostara seven-piece visual filter set

From: Optical Hardware Ltd

Cost: £59.99 (approx. $93)

Enhance your views of the Solar System with this seven-piece filter set, includes Moon, Polarising, Yellow, Orange, Red, Green and Blue filters for an observing experience like no other. If you want to see one of Mars's dust storms, Jupiter's Great Red Spot or the craters of the Moon, Ostara's visual filters can be used with most telescopes.

To be in with the chance of winning, all you have to do is answer this question:

NASA's Chandra X-ray Observatory is named after who?

A: Lalitha Chandrasekhar

B: Chandrasekhara Venkata Raman

C: Subrahmanyan Chandrasekhar

Enter online at: **spaceanswers.com/competitions** Visit the website for full terms and conditions

Visionary Mira Ceti 150 1400 telescope

From: Optical Hardware Ltd
Cost: £299.99 (approx. $463)
With its six-inch aperture, the Visionary Mira Ceti is the perfect companion to observe a wide range of night-sky targets, from planets to deep-sky objects. Complete with 25mm and 6.5mm eyepieces, as well as a Barlow lens and Moon filter, this compact and light Newtonian offers good portability.

The Practical Astronomer

From: Dorling Kindersley
Cost: £14.99 / $19.95
Written by astronomers Anton Vamplew and Will Gater, *The Practical Astronomer* helps you pick up all the basics of skywatching. Starting off your tour of the night sky simply, this book shows you how to recognise constellations and identify deep-sky and Solar System targets. *The Practical Astronomer* also provides advice on buying and using kit, from binoculars to telescopes.

WORTH OVER £1000!

DK
THE PRACTICAL ASTRONOMER
...NDERS OF THE NIGHT S...
FIELD OPTICS RESEARCH
ENHANCED OPTIC PERFORMANCE
Guy Consolmagno and Dan M. Davis

Visionary HD 10x50 binoculars

From: Optical Hardware Ltd
Cost: £109.99 (approx. $170)
Tour the night sky in high definition with these Visionary HD binoculars, ensuring bright images and excellent light gathering to pick out star clusters to the brightest planets. The 10x magnification allows these binoculars to double up as an aid for nature watching, ensuring high clarity, high power and a natural well-balanced image thanks to multicoated lenses and BAK4 prisms.

Turn Left At Orion

From: Cambridge University Press
Cost: £24.99 / $34.99
A must-have for any observer, *Turn Left At Orion* is a guidebook to the night sky, providing all the information needed to observe a host of celestial objects. Featuring a spiral bind, this edition is easy to use outdoors while using a telescope and is ideal for beginners - whatever observing equipment you have, whichever hemisphere you are in.

Field Optics Research Eyeshield

From: Optical Hardware Ltd
Cost: £19.99 (approx. $31)
An excellent product for anyone using binoculars or a telescope, the Eyeshield - made using a flexible moulded rubber material - fits comfortably around the eyes to block out any distracting light and wind, providing the skywatcher with total darkness and complete comfort for an outstanding observing experience.

Visionary Wetland 8x42 binoculars

From: Optical Hardware Ltd
Cost: £99.99 (approx. $154)
If you're an avid observer of the Moon, or general nature viewer, then these high-quality waterproof binoculars from Visionary are your ideal companion. Featuring twist eyecups along with coated lenses for great clarity and colour, the Visionary Wetland 8x42 binoculars can withstand the tough outdoors while also remaining light and easy for comfortable observing.

Malina was awarded the Order of Merit from the French Society for the Encouragement of Research and Invention

Frank J Malina

The rocketeer who laid the foundations for the space program

From an early age Frank J Malina was driven by the pursuit of knowledge in the face of adversity. Born in 1912 in Brenham, Texas, Malina's interest in the world of science led him to a degree in mechanical engineering from Texas Agricultural and Mechanical University. But what really piqued his interest was space travel and rockets, something that was scoffed at in the 1930s as belonging to the realm of science fiction.

Regardless of the critics, Malina followed his dreams and achieved a PhD in Aeronautics at the California Institute of Technology, focussing on rocket flight and propulsion. However, this did not come easily and Malina had to use all his intelligence and skill to persuade Theodore von Kármán, the professor of Aeronautics, to allow him to focus on such outlandish areas of study. The main focus of Malina's study was to produce a sounding rocket, one that carries instruments to space in order to conduct different scientific experiments.

Malina's pursuit of knowledge and drive to succeed soon attracted a group of like-minded students. The group of six became known around Cal Tech as the 'suicide squad' due to the dangerous lengths they went to and terrible failures they experienced while testing the designs of their rockets. Regardless, Malina and his group kept pushing their research forward and eventually moved their operations into what would later become the Jet Propulsion Laboratory. The group attracted the attention of the US Army Air Corps who agreed to fund the project.

With funds and support behind him, Malina was free to develop and explore the realms of rocket technology to his heart's content. In October 1945 Malina was finally able to witness one of his dreams become a reality when his WAC Corporal sounding rocket became the first US rocket to reach more than an 80-kilometre (50-mile) altitude and the first to reach the edge of space.

Although he had achieved a feat many told him was impossible, not everything was smooth sailing for Malina. Growing up during the Great Depression had caused Malina to have a negative view of capitalism, which he believed had failed. In his early student days he had expressed a passing interest in communism and labour activism. Throughout World War II Malina found himself under heavy criticism by the Federal Bureau of Investigation due to his communist sympathies and in 1946 bureau agents raided his house. Malina had also watched while his rocket development was instead being utilised for nuclear weapons and war.

By 1947 he'd had enough and moved to France, where he joined the fledgling United Nations as secretariat of the United Nations Educational, Scientific and Cultural Organization (UNESCO) working under the biologist Julian Huxley. By 1951 he was the head of UNESCO's division of scientific research. However, even though he had moved countries, Malina still found himself pursued by the FBI. America was determined to track down and condemn anyone who showed even the slightest of communist sympathies. Because Malina had not listed his Communist Party membership on a questionnaire while at Caltech he was declared a fugitive. Malina and his lofty dreams helped to lay the foundations for the US space program, but now if he returned to the country he would be arrested immediately.

A pacifist and artist at heart, Malina quit his position at UNESCO and instead decided to focus on his kinetic art. His art career was groundbreaking, with revolutionary work in the realm of light and motion. Perhaps most significant however was his founding of *Leonardo*, a research journal that combined his two greatest loves, art and science. *Leonardo* is still being published to this day, bringing together the talents of artists, students and scientists.

Malina enjoyed one final foray into the world of rocketry in the late 1950s when he helped found the International Academy of Astronautics. In 1963 he was elected president of the academy and, finally comfortable to return to his first love, drafted a plan for a Lunar International Laboratory where the greatest minds in science would work together for peaceful purposes in space. ●

All About Space

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COSMIC CON

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ASTRONAUT, SPACE
& ASTRONOMY EVENT

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&

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EVENT INFORMATION

The Event will consist of:

Free Space & Astronomy Talks
Astronaut Lectures & Panels
Astronaut Photoshoots
Gala Dinner & Astronaut Signings
Limited space for some of the above

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